XVI INTERNATIONAL GEOLOGICAL CONGRESS

GUIDEBOOK 19 - - - EXCURSION C-1

COLORADO

QE
1
I6
1933d
V 19

CONSERVATION BRANCH
RECEIVED
NOV 11 1933
GEOLOGICAL SURVEY

International Geological Congress
XVI session
United States, 1933

Guidebook 19: Excursion C-1

COLORADO

Prepared under the direction of
CHARLES W. HENDERSON
UNITED STATES BUREAU OF MINES

NOTED
NOV 11 1933
NORTHROP

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1932

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price 30 cents

This guidebook includes contributions by the following authors:

Charles W. Henderson, United States Bureau of Mines.
Junius Henderson, University of Colorado.
T. S. Lovering, United States Geological Survey.
W. S. Burbank, United States Geological Survey.
E. T. McKnight, United States Geological Survey.
G. F. Loughlin, United States Geological Survey.
C. H. Behre, jr., United States Geological Survey.
John W. Vanderwilt, United States Geological Survey.
Quentin D. Singewald, United States Geological Survey.
F. M. Van Tuyl, Colorado School of Mines.
C. E. Dobbin, United States Geological Survey.
J. Harlan Johnson, United States Geological Survey.

This guidebook is published under the auspices of the United States Geological Survey, but it is not a part of the Geological Survey's regular series of publications, and the opinions expressed in it and the use of nomenclature do not necessarily conform to Geological Survey usage.

CONTENTS

ILLUSTRATIONS

INSERTS

COLORADO

Prepared under the direction of CHARLES W. HENDERSON

GEOGRAPHY, HISTORY, AND MINERAL PRODUCTION OF COLORADO

By CHARLES W. HENDERSON

Colorado sits astride the Continental Divide. It is bounded by parallels 37° and 41° N. and meridians 25° and 32° west of Washington (approximately 102° and 109° west of Greenwich) and is therefore nearly rectangular, measuring 387 miles from east to west at the south and 23 miles shorter at the north, and 276 miles from north to south (623 to 586 kilometers by 444 kilometers). The total area is 103,498 square miles (268,060 square kilometers). Within its borders west of longitude 105° west of Greenwich are 50 mountains 14,000 feet (4,267 meters) or more high. The highest point within the State is in the central part, in Lake County (Mount Elbert, altitude 14,420 feet, or 4,395 meters), and the lowest point is in the southeastern part, in Prowers County, at the Kansas-Colorado boundary (Arkansas River, 3,350 feet, or 1,021 meters). The Rio Grande flows across the middle southern boundary of the State into New Mexico at an altitude of about 8,000 feet (2,438 meters). The North Platte River flows across the middle northern boundary into Wyoming at about 8,500 feet (2,590 meters).

The area included in Colorado comprises land acquired by the United States by the Louisiana Purchase from France in 1803, by the annexation of Texas in 1845, and by the cession from Mexico in 1848.[1]

For ages before the discovery of America Colorado was sparsely populated by the Indians. Those who make the trip to Mesa Verde National Park will see the cliff dwellers' abodes and will be close to the Ute Indian Reservation in Colorado and the Navajo Indian Reservation in New Mexico and Arizona. Thomas [2] has shown from Spanish records at Madrid that Spanish explorers from Mexico appear to have first visited the region that is now eastern Colorado during the middle of the seventeenth century and to have traversed southern, central,

---

[1] See Douglas, E. M., Boundaries, areas, geographic centers, and altitudes of the United States and the several States: U. S. Geol. Survey Bull. 817, p. 40, 1930.

[2] Thomas, A. B., Spanish expeditions into Colorado: Colorado Mag., vol. 1, No. 7, November, 1924.

and western Colorado in 1706, 1719, 1720, 1765, 1776, and 1779. After 1779 the Spaniards and Mexicans were well acquainted with southern and southwestern Colorado. Frenchmen from Illinois crossed the eastern part of the State as early as 1693; and French fur trappers afterwards were frequent visitors to eastern Colorado and penetrated into central Colorado. American fur trappers knew the country well at least as early as 1800. The American business enterprise (1812 to 1873) of supplying goods from Missouri River points to the Mexicans and Indians at Santa Fe, New Mexico—an enterprise that built up the wagon trail to Santa Fe—affected only the southeast corner of Colorado; and the immigrants and missionaries to Oregon in 1812 to 1860 made a trail through the northeastern part of the State.

Exploring expeditions organized by the United States Government, beginning in 1806, gradually reached back into central and western Colorado. These expeditions included trappers and Indian guides and mainly followed the old trails, which were originally Indian trails. Capt. Zebulon Montgomery Pike, United States Army, explored the south-central part of the State in 1806 and 1807; Maj. Stephen H. Long, United States topographic engineer, traversed the eastern plains as far west as Canon City in 1820; Col. Henry Dodge, United States Army, in 1835 followed nearly the same route as Long; the expeditions of John C. Frémont, between 1842 and 1853, reached into the mountains; Capt. John W. Gunnison and Lieut. E. G. Beckwith, searching for a railroad route to the Pacific Ocean, in 1853 went north through San Luis Valley, over Cochetopa Pass, and down the Gunnison River to the junction of the Gunnison and the Grand (now the Colorado).

Although the Spaniards were in search of gold and silver such as they had found in Peru and Mexico, they found none in Colorado and little in New Mexico. Nor did the trapper or the United States Government expeditions discover gold. As the great transcontinental migration to the California gold mines that began in 1849 found the high mountains in Colorado a barrier to travel, the main avenues to the far West were the Oregon Trail, through Wyoming, on the north, and the Santa Fe Trail, through New Mexico, on the south. The Santa Fe Trail had a northern branch or mountain division through southern Colorado and over Raton Pass. There was also a little-used trail between the Santa Fe Trail and the Oregon Trail. If hunters, trappers, and Indians knew of gold in Colorado before 1849, their knowledge led to no immigration.

The Russell brothers, to whom nearly all historians now credit the rush to the Pikes Peak region in 1858, had gained experience in placer gold mining in California. They led a party of

Georgians, Cherokee Indians, and others to Cherry Creek (now Denver) in 1858 in search of gold in what was then western Kansas. The Russell party found colors of gold all along Cherry Creek, at the mouth of Ralston Creek, and in Dry Creek, 3½ miles up the Platte River, south of Cherry Creek; but the discoveries were disappointing. Nevertheless, some of the men

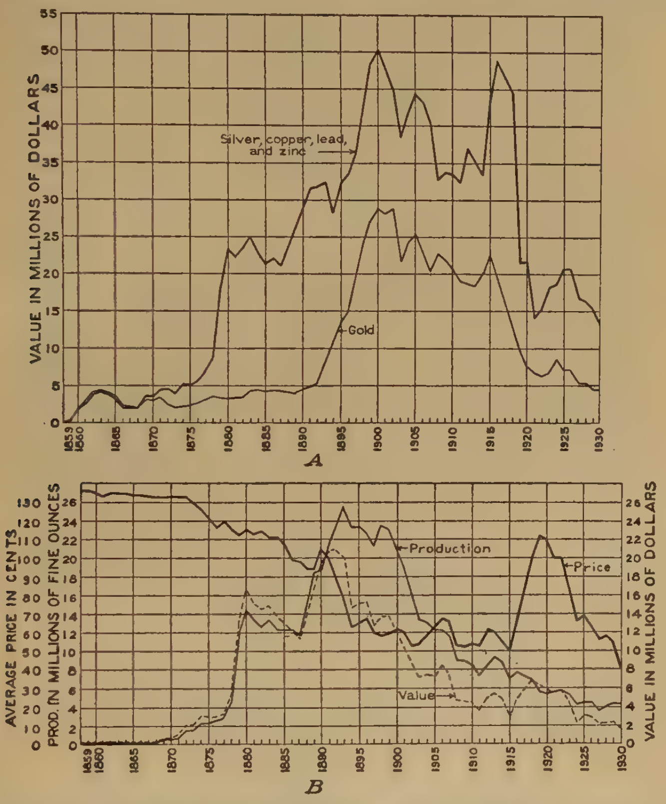


FIGURE 1.—Curves showing metal production of Colorado. *A*, Gold, silver, copper, lead, and zinc; the upper curve includes gold also. *B*, Silver

of this party and others who had come to Cherry Creek, in the "Pikes Peak gold region," remained through the winter and prospected into the hills. On January 7, 1859, George A. Jackson found placer gold on South Clear Creek (later called Chicago Creek), near the present town of Idaho Springs. On May 7, 1859, John Gregory found easily worked oxidized outcrops of veins on North Clear Creek, soon called Gregory Diggings,

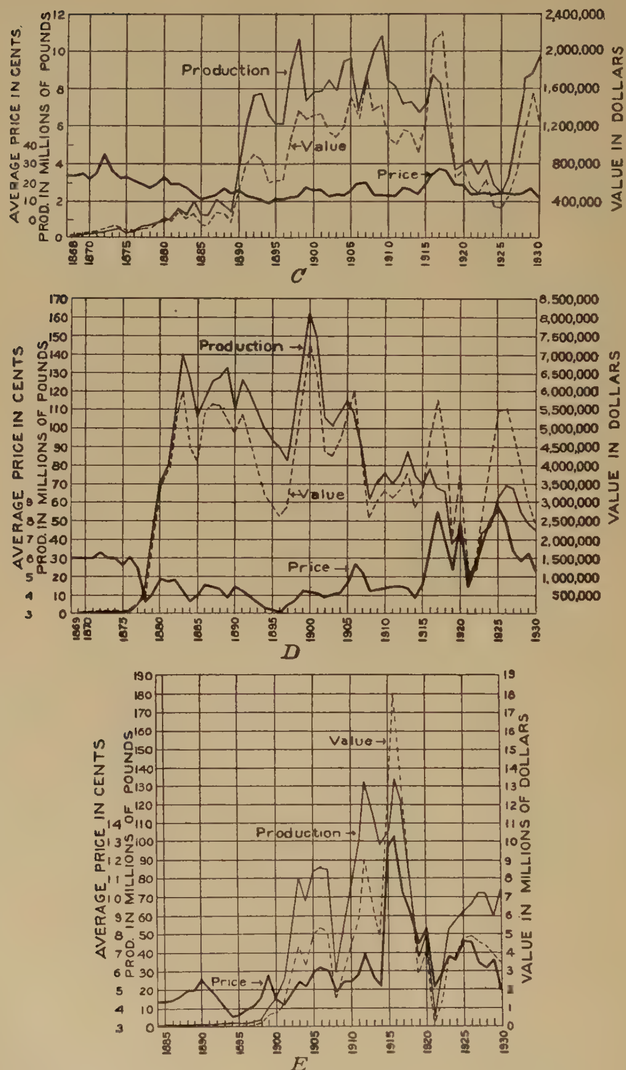


FIGURE 2.—Curves showing metal production of Colorado. *C*, Copper; *D*, lead; *E*, zinc

near the spot where later rose the town of Black Hawk. The financial panic of 1857 was still felt in the United States, and a rush started for the Gregory Diggings. Other diggings were found in 1859. A second immigration (or rush) occurred in 1860, larger than the one in 1859. The immigrants made settlements. The Civil War reduced immigration, but silver ore was discovered in 1864. Wild hay was found in the mountain parks, coal was discovered and coal mines opened, and agriculture and cattle raising began. In 1867 the Union Pacific Railroad was completed from Omaha to Cheyenne, and in 1870 a railroad was built from Denver to Cheyenne and the railroad from Kansas City to Denver was completed. In January, 1868, a copper matte smelter was opened for business, and in June its first shipment of matte was made, to Swansea, Wales. The rest of the story for gold, silver, copper, lead, and zinc is told in the graphs shown in Figures 1 and 2.

The total production of the most important metals and minerals found in Colorado, calculated at average yearly prices per unit of sale, from 1859 to 1930, is as follows:

Gold (34,611,248 ounces [3])	$715,478,000
Silver (657,839,654 ounces [3])	518,490,000
Copper (304,513,430 pounds [3])	46,256,000
Lead (4,593,958,583 pounds [3])	217,175,000
Zinc (2,198,137,985 pounds [3])	155,723,000
Coal (347,696,000 short tons)	711,500,000
Tungsten	19,525,000
Radium	18,000,000
Petroleum	29,362,000
Molybdenum	13,293,000
Vanadium	6,906,000
Fluorspar	2,053,000
Iron	3,916,000
Manganese	4,207,000
	2,461,884,000

LIFE ZONES, FAUNAS, AND FLORAS OF COLORADO

By Junius Henderson

In Colorado great differences in altitude and topography strongly influence temperature and precipitation and result in marked climatic zones. The climatic differences affect the distribution of various types of plants and animals, and hence several life zones are represented.

1. The upper Sonoran or plains zone extends up to about 5,500 feet (1,676 meters) above sea level in northern Colorado and to about 7,800 feet (2,377 meters) in southern Colorado. It includes the plains of eastern Colorado and the lowlands and

[3] In terms of recovered refined metal.

mesas of southern and western Colorado and of the mountain parks (valleys). The eastern plains are destitute of forests, but willows (*Salix*) and broad-leafed cottonwoods (*Populus*) fringe the streams and irrigation canals. The unplowed plains consist chiefly of grasslands, but some large areas are covered with sage (*Artemisia*). Many mesas bordering the mountains in southern and western Colorado support forests of cedar and piñon, and some are covered with a dense growth of sagebrush and other shrubs.

2. The transition or foothill zone, 5,500 to 7,500 feet (1,676 to 2,286 meters) in northern Colorado and 8,000 to 9,000 feet (2,438 to 2,743 meters) in southern Colorado, includes the foothills of the mountain ranges. The dominant trees are rock pines (*Pinus*), in open forests and groves. The broad-leaved cottonwoods of the lowlands give way to narrow-leaved cottonwoods along the canyon streams.

3. The Canadian or montane zone, about 7,500 to 10,000 feet (2,286 to 3,048 meters) in northern Colorado and 8,000 to 11,000 feet (2,438 to 3,352 meters) in southern Colorado, is the belt of mountains lying above the foothill zone. It bears lodgepole pines, firs (*Abies*), spruces (*Picea*), and aspens (*Populus*), in dense forests in many localities.

4. The Hudsonian or subalpine zone, 10,000 to 11,000 feet (3,048 to 3,352 meters) in northern Colorado, and 10,500 to 11,500 feet (3,200 to 3,505 meters) in southern Colorado, lying above the Canadian zone, extends to timber line. The upper part of this zone is characterized by dwarfed, gnarled, distorted conifers, many of them prostrate upon the ground.

5. The arctic-alpine zone extends from the upper limit of trees, at about 11,000 feet (3,352 meters), to the tops of the highest mountains.

Excellent examples of the influence of geologic conditions upon the distribution of plant life may be seen in the foothills. The rock pines commonly extend along rocky ridges but seldom invade the deep, loose soil at the foot of a slope. In the foothills west and northwest of Fort Collins, the shrub mountain mahogany (*Cercocarpus montanus* Rafinesque) covers most of the steep dip slopes of sandstone, giving way to grassland where the soil becomes deeper and finer at the foot of the slopes.

The life zones exhibit differences in the distribution of shrubs and herbaceous plants and of animal life, as well as in the distribution of trees. Thus the columbine (*Aquilegia caerulea*), Colorado's State flower, is confined to the mountains. In the highest mountains, conies or pikas (*Ochotona*) "bark" among the rocks of talus piles, and mountain sheep (*Ovis*) are not uncommon. At somewhat lower levels the wapiti or American elk

(*Cervus*) occur in many localities. The mule deer (*Odocoileus hemionis*) ranges from timber line to the foothills. The western white-tailed deer (*O. americanus macrourus*), once common on the plains, is now seldom seen and is confined to a few isolated localities. Bears (*Ursus*) and mountain lions (*Felis*) are confined almost entirely to the mountains. Most of the bobcats (*Lynx*) are also found in the mountains, although some are found in the foothills. The prong-horned antelope (*Antilocapra*), one of America's most interesting mammals, is still somewhat common in parts of the plains and open parks.

The American bison or "buffalo" (*Bison bison*), once very abundant on the plains and common in the mountains up to timber line, is not now known in the State, except in captivity. Coyotes are common and larger wolves rare from the plains to timber line. Foxes are confined chiefly to the mountains. The snowshoe rabbit or varying hare (*Lepus bairdi*) is found in the higher mountains, but jack rabbits (*Lepus* of several species) are mostly confined to the plains, although they are not absent from open mountain parks or even from the treeless zone above timber line. Cottontail rabbits (*Sylvilagus*) occur in the mountains. The beaver (*Castor*) is still common in many places, and the muskrat (*Fiber*) more common, from the plains to timber line. Prairie dogs (*Cynomys*) of several species occur in colonies on the plains and in some of the open mountain valleys. Pine squirrels (*Sciurus*) are common in conifer forests, chipmunks (*Eutamias*) of several species are abundant in many localities from plains to timber line, rock squirrels (*Citellus*) range from 8,500 feet (2,591 meters) to the foothills, striped spermophiles (*Citellus*) are found mostly on the plains, and badgers (*Taxidea*) occur from the plains to timber line. Raccoons are seldom seen. Skunks and weasels are common, and minks less so. Many species of mice and other small rodents are abundant, and various species of rats, shrews, and bats are common.

Birds, many species of which have migratory habits, range widely over the State as a rule, although there are exceptions. The ptarmigan (*Lagopus*) lives above timber line in the summer and not far below timber line in the winter. The dusky grouse (*Dendragupus*) is found in the Canadian zone and the upper part of the transition zone. The handsome long-crested jay (*Cyanocitta*), often erroneously called the blue jay, resides chiefly in the foothills and lower mountains, and two other striking members of the family, Clark's nutcracker (*Nucifraga*) and the Rocky Mountain jay (*Perisoreus*), both called camp robbers, range somewhat higher. Piñon jays (*Cyanocephalus*) and Woodhouse's jays (*Alphelocoma*) often occur in large flocks, the former preferring piñon forests, though wandering widely.

The magpie, a large, striking black and white long-tailed species, is one of the most conspicuous and frequently seen birds on the plains and in the mountains up to 9,500 feet (2,896 meters). The thick-billed redwing blackbird (*Agelaius*) is abundant and Brewer's blackbird (*Euphagus*) is common on the plains and in the lower mountains, while the yellow-headed blackbird (*Xanthocephalus*) is seldom seen in the mountains. The western meadow lark (*Sturnella*) and mourning dove (*Zenaidura*) range from the plains well up into the mountains. The dipper, or water ouzel (*Cinclus*), one of the most interesting of American birds—a song bird that enters the swiftest water for its food—may be seen along many mountain streams. The pipit may be observed "bobbing" along high mountain lake shores. The most conspicuous of the Colorado woodpeckers, the red-shafted flicker (*Colaptes*), breeds from the plains nearly to timber line. Other common woodpeckers of the mountains are the hairy, downy, and Lewis woodpeckers and the sapsuckers. The red-headed woodpecker occurs on the plains. One of the most common town birds is the house finch (*Carpodacus*). The water birds and shore birds are found mostly on the plains, although some species occur high in the mountains. More than 400 species and subspecies of birds have been reported in Colorado, most of them small and inconspicuous.

GEOLOGY OF COLORADO

By T. S. Lovering

STRATIGRAPHY

Pre-Cambrian rocks.—Throughout the State (see pls. 1 and 2) the most ancient rocks now exposed are highly metamorphosed sedimentary rocks. They consist chiefly of quartz-biotite schist, quartz-biotite-sillimanite schist and gneiss, and injection gneiss. Extensive but lenticular masses of hornblende gneiss, hornblende schist, and greenstone occur at many places and are everywhere later than the main mass of the earlier schists and gneisses. These basic schists and gneisses are probably metamorphosed andesitic lavas and dioritic sills.

In the Needle Mountain uplift and near Ouray, in the western San Juan Mountains, occurs a series of slates, quartzites, and conglomerates that are considered to be of Algonkian age. They are definitely younger than the greenstone series and the early schist series. Much of the granite in this region is known to be younger than the slates and quartzites. In the pre-Cambrian terrane north and northeast of the San Juan Mountains the early

schists and greenstones are present, but no quartzites and slates corresponding to those of the Needle Mountains have been recognized. The granites are younger than the greenstone gneisses.

There are many different types of pre-Cambrian granite, but probably nearly all were intruded during one batholithic cycle. In most places the earliest pre-Cambrian granitic rocks are moderately coarse grained gneissic biotite granite or biotite-quartz monzonite and are accompanied by pegmatite and dioritic differentiates. The largest granite masses were formed somewhat later and are commonly coarse-grained pink biotite granite, showing little gneissic structure. The pegmatite associated with granite of this type contains many unusual minerals in the region near Colorado Springs. Many stocks and small batholiths of fine-grained or light-colored granite intrude the older ones. All the pre-Cambrian granites are cut by pegmatite and aplite of approximately the same age as the fine-grained late granites.

In southwestern Colorado pre-Cambrian sedimentary rocks occur which Cross believes may be later than some of the pre-Cambrian granites. In the northwest corner of the State there is a thick series of unmetamorphosed sandstones and quartzites which are not cut by granitic rock. These sediments are probably later than the batholithic cycle and are thought to be of late Algonkian or, in part, early Cambrian age.

Cambrian.—The Cambrian sedimentary rocks are chiefly quartzitic sandstones, but some thin-bedded shale, limestone, and flat-pebble limestone conglomerate are present. (See pl. 2.) In Paleozoic time the Cambrian sediments occupied two northwestward-trending belts in the southwest half of the State. The most extensive deposits (the Sawatch quartzite) were formed in the central Colorado basin, extending northwestward from the vicinity of Pueblo to the region near Glenwood Springs. The other area of Cambrian sedimentation occupied the southwest corner of the southwestern Colorado basin, and in that region the Cambrian quartzite is known as the Ignacio quartzite.

The central Colorado basin and the southwestern Colorado basin were separated by the Uncompahgre highland, upon which there is no evidence of Cambrian sedimentation. No Cambrian rocks have been found north of the central Colorado basin, and it is probable that in most of that region none were deposited. Uplift in late Paleozoic time and folding in the early Tertiary destroyed the unity of the central Colorado basin, and since that time erosion has removed large masses of Cambrian rocks in central Colorado.

Ordovician.—Ordovician beds are confined entirely to the central Colorado basin. They overlap the Cambrian quartzite at

several places along the southern edge of the central Colorado basin and at a few places along the eastern border of the Front Range near Canon City. Much of the Ordovician system is limestone, but a sandy formation, the Harding sandstone, is commonly present in the middle of the system, and sandy and cherty beds occur at the base in and near the region where the Ordovician overlaps the Cambrian sediments. The Harding sandstone lies between Lower Ordovician and Upper Ordovician limestones and contains fossils that are considered to be of Middle Ordovician age (13).[4] It is noteworthy for containing fish bones and plates in the Canon City district and other localities. The Upper Ordovician beds are locally sandy or quartzitic near the northern edge of the central Colorado basin. This is probably a shore facies and suggests an overlap to the northeast. Beds of this type are well exposed near Red Cliff and Gilman. (See p. 71.)

Silurian.—No Silurian beds are present in Colorado.

Devonian.—The general distribution of Devonian sediments is similar to those of the Cambrian. The fossils found in the Elbert formation and the Ouray limestone in the southwestern Colorado basin indicate that the beds are Upper Devonian. There was no sharp break between Devonian and Mississippian sedimentation in that region. Devonian fossils are rare in the central Colorado basin, but the identification in many areas of the Chaffee formation, which underlies the Mississippian Leadville limestone and which in places contains the same invertebrate fauna as the Devonian Ouray limestone of southwestern Colorado (14), indicates the presence of Devonian rocks throughout most of the basin. The Devonian sediments are thin-bedded sandstone and shale at the base but for the most part are limy or dolomitic.

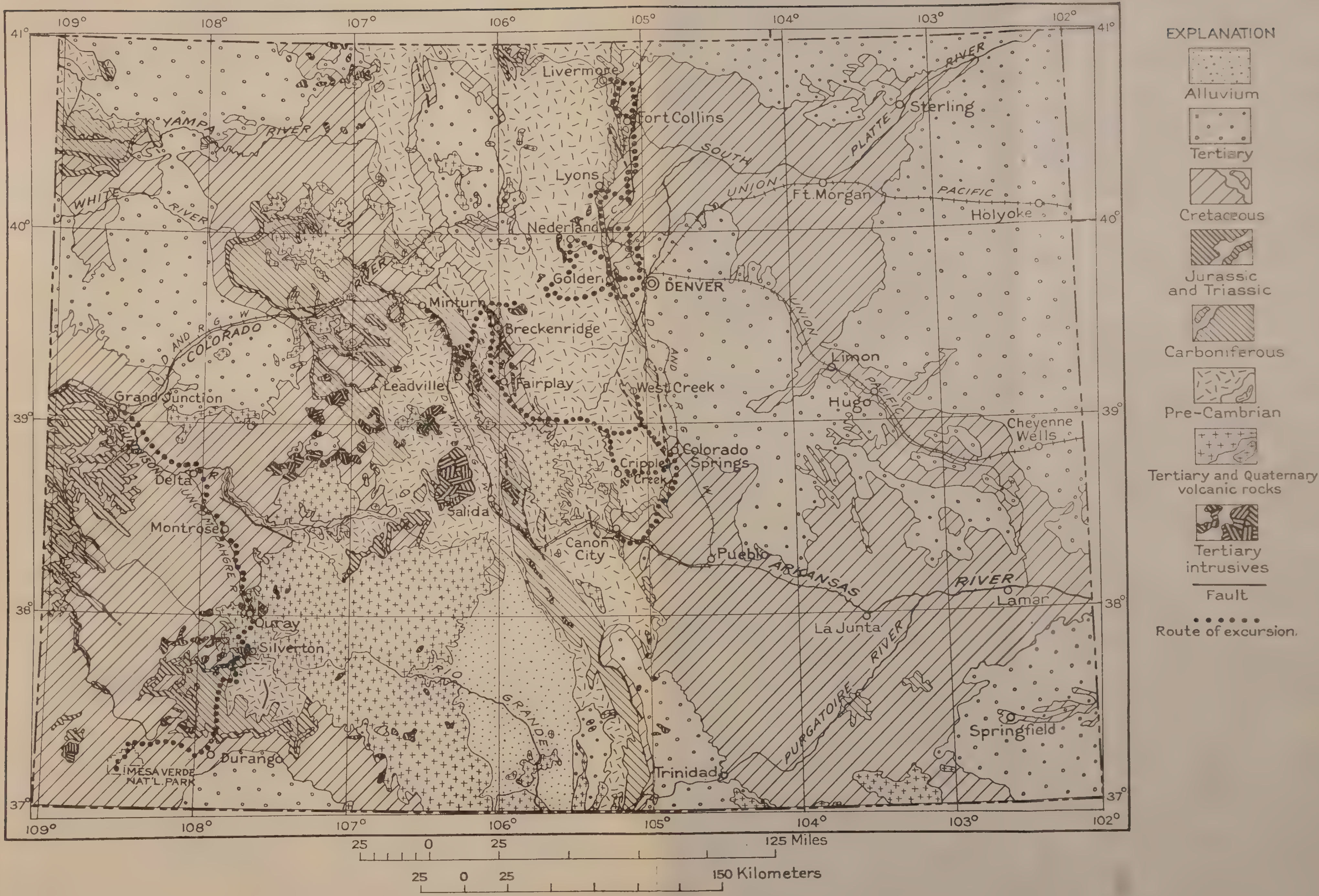
Mississippian.—The fossiliferous Mississippian Leadville limestone is found in both the southwestern Colorado basin and the central Colorado basin. Although conformable with the underlying Devonian rocks, it is separated from the overlying Pennsylvanian formations in most places by an unconformity.

The Leadville limestone is the chief host rock for replacement ore deposits in Colorado. Most of the ore produced at Leadville, Gilman, and Aspen has been found in this formation.

Pennsylvanian.—The highlands bordering the central Colorado basin and the southwestern Colorado basin were uplifted at the end of Mississippian time. Along the margins of these basins Pennsylvanian rocks overlap all the older formations with marked unconformity.

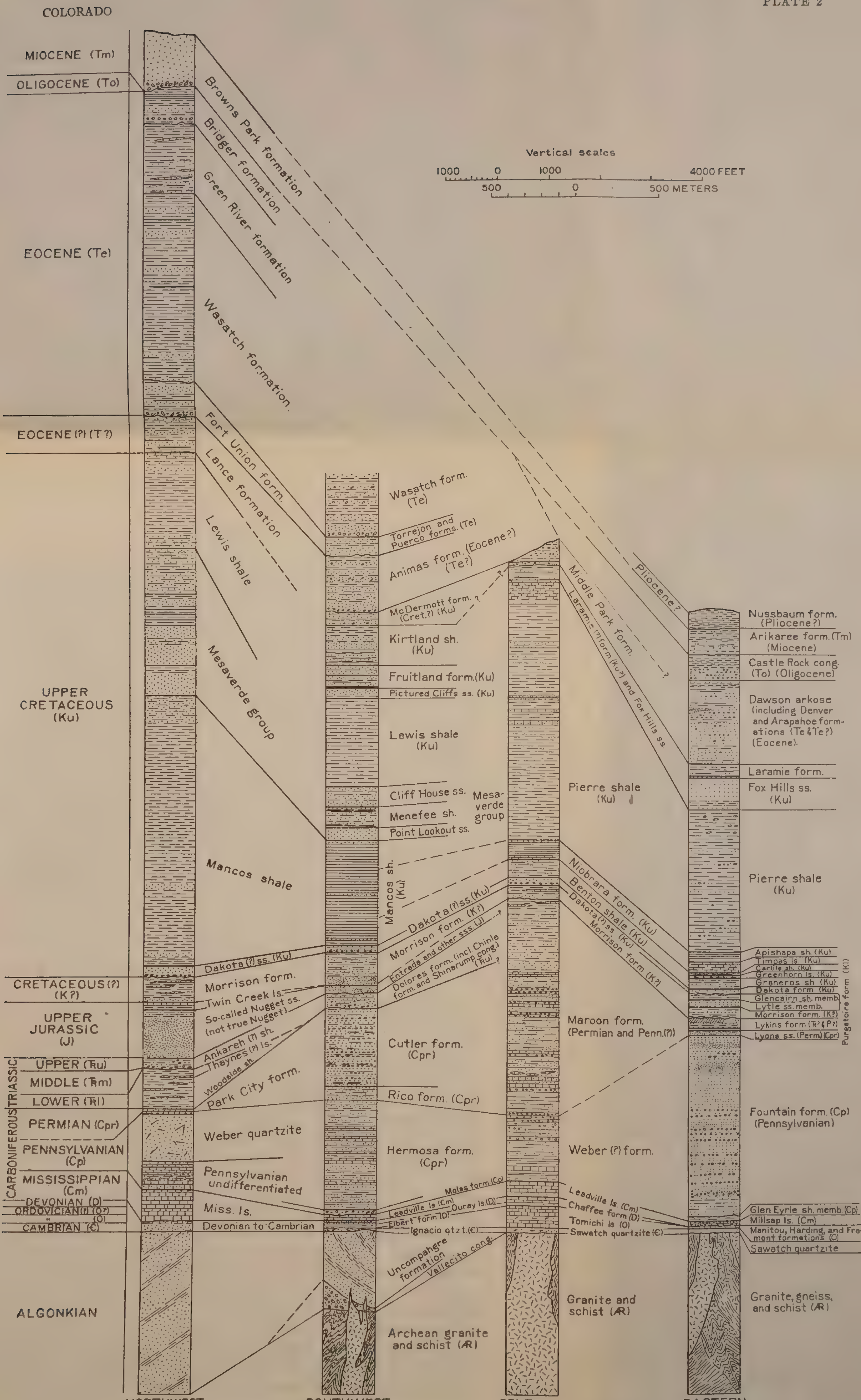
---

[4] Numbers in parentheses refer to general bibliography, pp. 25–26.



GEOLOGIC MAP OF COLORADO

Generalized from geologic map of the United States, compiled by G. W. Stose.



GENERALIZED COLUMNAR SECTIONS FOR COLORADO

Pleistocene and Recent sedimentary formations and Tertiary volcanic rocks not shown.

In the central parts of the basins the lowest Pennsylvanian rocks are marine shales and limestones interbedded with coaly shales containing abundant plant remains. Grit and conglomerate overlie the lower member. In the lower part of the grit series beds containing a marine Pennsylvanian fauna are interstratified with beds containing lower Pennsylvanian floras. Beds containing a Permian flora appear about 1,500 feet (457 meters) from the base of the Pennsylvanian and overlie a limy member characterized by *Fusulina* and threadlike algae. The Permian plant beds are interlayered with marine beds containing a fauna which has been considered of Pennsylvanian aspect.

There is no sharp stratigraphic break between the Pennsylvanian and the Permian beds in Colorado, and the great number of minor unconformities present in the grit makes it difficult to recognize a regional unconformity or to correlate Pennsylvanian and Permian beds in different parts of the State. In general the Pennsylvanian is light and dark gray, and in many places the Pennsylvanian grits may be distinguished from the overlying red Permian beds by their color. In southwestern Colorado the thin red basal formation of the Pennsylvanian (the Molas formation) is overlain by dark and light gray shale, sandstone, limestone, and grit (the Hermosa formation), followed by the red beds of the Permian (Rico and Cutler formations).

In the northwestern part of the central Colorado basin the lower Pennsylvanian beds are overlain by the Weber (?) quartzite, of middle (?) Pennsylvanian age, which is succeeded by the Park City formation, of upper Pennsylvanian and Permian age. These formations disappear toward the southeast and are overlapped by Permian grits that apparently rest on the Weber (?) formation (grits and shales), of lower Pennsylvanian age, throughout central Colorado. On the east side of the Front Range the red grits of the Fountain formation, which are of Pennsylvanian age, extend north of the central Colorado basin to the Wyoming line and south of the basin to the New Mexico line. They are predominantly red and range in thickness from 100 feet (30 meters) to about 2,000 feet (610 meters).

Throughout the State the Pennsylvanian grits are characterized by abundant clastic mica and by pre-Cambrian débris. Gypsum beds are common in the upper part of the Pennsylvanian section in central and southwestern Colorado. Several salt domes have been found in Pennsylvanian strata in the Paradox Valley region, in the southwestern part of the State.

Permian.—The distribution of Permian rocks in Colorado is very similar to that of the Pennsylvanian beds and is shown in

113723—32——2

Figure 3. Although they are chiefly coarse red grits, conglomerates, and micaceous sandstones, limestones are not uncommon in the lower part of the Permian section and red micaceous shales are common in the upper part. No undoubted Permian invertebrates have been found in these rocks, but a characteristic Permian flora has been found in several places. The flora thus far discovered indicates lower Permian or early middle Permian age. The Permian beds in southwestern Colorado are known as the Rico and Cutler formations; those east of the

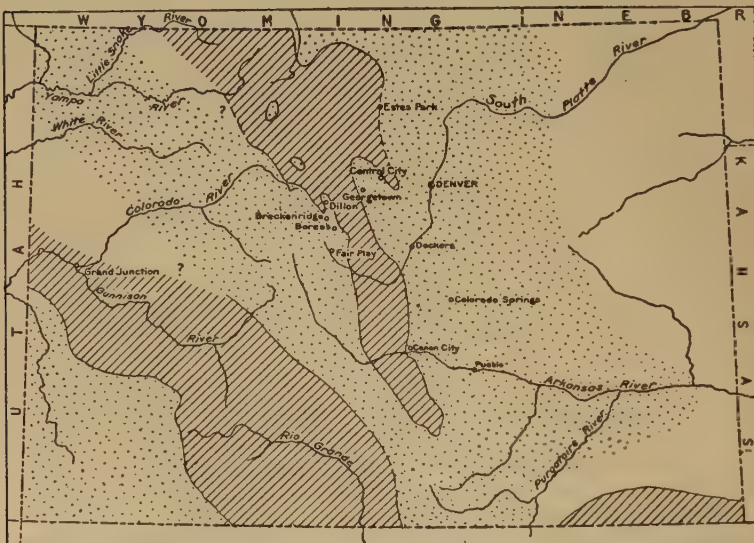


FIGURE 3.—Paleogeography of the Permian rocks of Colorado at beginning of Triassic time. Ruled areas, highlands; stippled areas, Pennsylvanian and Permian rocks. (From Colorado Sci. Soc. Proc., vol. 12, No. 4, fig. 3, 1929)

Front Range as the Lyons sandstone, although the lower part of the overlying Lykins formation may also be of Permian age. In parts of the central and southwestern Colorado basins and east of the Front Range gypsum is common in the Permian rocks.

Triassic.—No Triassic formations are certainly known in the eastern half of Colorado, but the sandstones, red shales, and muddy limestones of the lower part of the Dolores formation of the southwestern Colorado basin are of Triassic age, as are also the contemporaneous beds of the Chinle formation of central western Colorado. In a small part of central western Colorado

the lower Triassic Moenkopi formation also occurs. Marine shales, limestones, and sandstones of Lower Triassic age (Woodside shale and Thaynes limestone) are present in the northwestern part of the State and are overlain by Upper Triassic red beds (Ankareh? formation). Red shales and orange-colored sandstones of Upper Triassic age are found in north-central Colorado and the upper and major part of the Lykins formation of northeastern Colorado is regarded as probably of Triassic age. The maximum thickness of the Triassic beds in Colorado is about 1,000 feet (305 meters).

Most or all of the Triassic sedimentary rocks of Colorado are of continental origin. Few Triassic fossils have been found in Colorado, although some vertebrate remains, chiefly of crocodiles and turtles, have been collected in the northern and central parts of the State. Gypsum is not as abundant as in the underlying Pennsylvanian and Permian formations.

Jurassic.—The distribution of the Jurassic sediments is very similar to that of the Triassic. In the southwestern part of the State the Jurassic sandstone overlaps truncated Triassic folds and in places rests upon the pre-Cambrian. In central Colorado the Jurassic sediments do not extend as far east as the Triassic, and the Morrison formation, of Lower Cretaceous or Upper Jurassic age, overlaps the known marine Jurassic and rests directly on the Triassic.

In western Colorado, south of the Colorado River, the basal Jurassic consists of the reddish massive cross-bedded, limy Wingate sandstone. This is overlain by various Jurassic sandstones, most commonly by the buff to white Entrada sandstone but at some places by the soft red Kayenta formation, the massive white Navajo sandstone, and the soft red Summerville formation. From west to east across the Uncompahgre Plateau into the San Juan Mountains the higher Jurassic beds overlap the lower ones, and in the San Juan Mountains the Upper Jurassic Entrada sandstone rests directly on the Triassic. In the central Colorado basin the Jurassic is represented by the Entrada sandstone only. In northwestern Colorado the Entrada, according to J. B. Reeside, has been called, in error, the Nugget sandstone. It includes 950 feet (290 meters) of white and buff cross-bedded, medium-grained sandstone, and is overlain by the Twin Creek limestone, an Upper Jurassic marine limestone about 125 feet (38 meters) thick. These beds thin out toward the east and disappear west of the western front of the Park Range.

No undisputed Jurassic deposits except the marine Upper Jurassic (Sundance formation) are known in eastern Colorado, and the Sundance is present in only a very small area in northeastern Colorado.

Cretaceous (?).—Continental deposits of either Upper Jurassic or Lower Cretaceous age, known as the Morrison formation, have a wide distribution in Colorado and probably once covered the whole State except small portions of the highlands along the southwest and northeast sides of the central Colorado basin. The lower part of this formation is chiefly sandstone with some interbedded limestone and shale, and in the western part of the State gypsum occurs near the bottom of the section. The upper half of the formation is largely variegated shale but contains interbedded limestone and sandstone. Green, purple, gray, and red shales are prominent and give the formation a characteristic appearance, which is easily recognized. Beds of this age overlap the older formations extensively and rest upon the ancient crystalline rock at many places near the borders of the southwestern Colorado and central Colorado basins.

The age of the Morrison formation is debatable. The most abundant fossils in the formation are swamp-loving reptiles (dinosaurs), which are referred to the Lower Cretaceous by some paleontologists and to the Jurassic by others.

Lower Cretaceous.—The Purgatoire formation, comprising marine beds of Lower Cretaceous age, is found in southeastern Colorado. The lower half of the formation generally consists of a white sugary sandstone, which grades upward into a brown and buff cross-bedded sandstone. The upper third of the section is generally a black to gray shale. The formation carries the characteristic fauna of the upper or Washita division of the Comanche series.

Upper Cretaceous.—Upper Cretaceous beds formerly covered all of Colorado, though it is probable that the basal formation, the Dakota sandstone, was not deposited everywhere. The persistent basal formation of the Upper Cretaceous is chiefly an even-grained white to buff sandstone but commonly contains interbedded black shale, fire clay, and thin beds of conglomerate made up largely of chert and quartz pebbles. Except in southeastern Colorado the Dakota sandstone is underlain in most places by the variegated shales of the Morrison formation, but locally it overlaps older beds and rests directly on the pre-Cambrian. Plant remains are common in the basal sandstone, but few vertebrates or invertebrates have been collected.

The Dakota sandstone is everywhere overlain by a few hundred feet of black or dark-gray clay shale of Benton age. In most places this shale is overlain by gray limestone and limy shales of Niobrara age, from 300 to 600 feet (91 to 183 meters) thick. The Niobrara limestone can be recognized as a distinct unit only in the eastern two-thirds of the State, and, as its lithology is the same as that of the underlying strata of Benton

age, in the southwestern Colorado basin and in the northwestern part of the State the strata of Benton and Niobrara age are included, together with younger strata of early Pierre age, in the great mass of dark-gray marine shales known as the Mancos shale.

In the eastern half of the State a thick shale formation, the Pierre shale, overlies the Niobrara strata. It contains comparatively little sandstone or limestone, but as it is followed westward sandstones appear and become more abundant. In western Colorado the sandstones and interbedded shales that overlie the Mancos shale are called the Mesaverde group where differentiated into several units and the Mesaverde formation where not differentiated. Both marine and nonmarine sandstones are present in the Mesaverde rocks, and much of the coal of western Colorado is found in the nonmarine sandstones of this age. Above the coal-bearing sandstones in the western part of the State both marine and nonmarine shales and sandstones occur. A persistent series of sand and sandy shale overlies the Pierre shale in the eastern half of the State. These strata are known as the Fox Hills sandstone in northern Colorado.

This series of sandstones contains coal and fresh or brackish water fossils in southeastern Colorado but is of marine origin in the north, where it is overlain by later continental coal-bearing rocks known as the Laramie formation. In the southern third of the State the Laramie and Fox Hills strata are included in the Vermejo formation. At many places the beds of Laramie age were wholly or partly eroded before the overlying Tertiary formations were deposited.

In southwestern Colorado the coal-bearing Mesaverde beds are overlain by marine shales (Lewis shale) succeeded by sandstones (Pictured Cliffs sandstone), which in turn underlie brackish-water coal-bearing shales and sandstones (Fruitland and Kirtland formations) that are of approximately the same age as the lower part of the Vermejo formation of southeastern Colorado. A thick series of Upper Cretaceous (?) andesitic tuffs, sandstones, and shales (McDermott formation) rests upon the Kirtland shale unconformably. These beds mark the beginning of a long period of volcanic activity that was the first of importance in Colorado since pre-Cambrian time. The volcanism, which began in late Cretaceous time in the San Juan Mountains (if the Cretaceous age of the McDermott formation is accepted), gradually spread northeast to the Front Range. Volcanic centers appeared a short distance west of the Boulder-Denver sector of the Denver Basin and supplied the andesitic material in the Denver, Dawson, and associated formations, which are now classified by the Geological Survey as Eocene.

Eocene.—The formations just mentioned are separated from the underlying Cretaceous formations by an erosional unconformity, but there is little discordance in the dips of the two series of sediments. The first volcanic activity since pre-Cambrian time in the Front Range region began at this time, and most of the sediments of this age contain volcanic débris intermingled with fragments of the older sedimentary rocks and the pre-Cambrian metamorphic rocks. In Middle Park and near Denver lavas are interstratified in this part of the column, and tuffs are common in rocks of this age in the San Juan region as well as in the Middle Park, North Park, and Denver Basins. Shales are common in the upper part of the section near the mountains and throughout the section in the region farthest from them. Locally the shales contain workable coals.

The most abundant vertebrates found in this group of rocks in Colorado are ceratopsian and other dinosaurs; they also contain an abundant fossil flora.

In the San Juan Mountains a pre-Miocene glacial till (Ridgway till) rests unconformably upon folded Cretaceous rocks. This till contains many pebbles of the andesitic porphyries which are abundant in the late Cretaceous and early Eocene sediments of the San Juan Mountains, and it is cut by a peneplain which is probably of late Eocene or early Oligocene age. Andesitic pebbles have not yet been found in the younger Wasatch and Green River formations, although they contain much pre-Cambrian débris. Because of its stratigraphic and structural relations and its lithology the Ridgway till is assigned to the Eocene.

Later Eocene formations are confined to the western half and the south-central part of the State. They are separated from the older beds by a marked angular unconformity, and it is probable that the major folding of the Rocky Mountains in Colorado occurred just before the deposition of the Wasatch sediments. Above a basal conglomerate the Eocene formations consist chiefly of variegated clay shale. The peculiar badland topography characteristic of the Eocene sediments is in part due to the presence of more resistant sandstones and grits. The middle part of the Eocene section (Wasatch and Green River formations) contains many beds of oil shale that crop out over wide areas in northwestern Colorado and the adjacent parts of Wyoming and Utah. The Eocene sediments of the Huerfano Park region, in south-central Colorado, contain no oil shale and have much more sandstone and conglomerate than the Eocene formations in the northwestern part of the State.

Eocene volcanism.—Volcanic activity preceded and accompanied the mountain building of early Tertiary time. The late Cretaceous and early Eocene volcanic activity in the San Juan

Mountains and the Front Range has been mentioned. Most of the early extrusive rocks were formed before the end of early Eocene time, but there are some areas of volcanic rocks which may be of later Eocene age. The intrusive rocks of late Cretaceous and early Eocene age are abundant in a narrow diamond-shaped area extending from the San Juan Mountains to the east side of the Front Range near Boulder. (See pl. 4.)

The extrusive rocks range in composition from basalt to rhyolite, and the intrusives from gabbro to granite. The earliest intrusives are moderately basic porphyries, accompanied in a few places by small amounts of ultra-basic porphyry. Neither of these types is abundant, however. After the intrusion of the basic rock, dikes and sills of diorite and monzonite were intruded extensively. The monzonites were followed by dikes, stocks, and small batholiths of quartz monzonite porphyry, which are definitely later than the thrust faulting that accompanied the mountain building of the Front Range. These rocks are cut by a peneplain which was developed before Oligocene time.

Mineralization followed the intrusion of the Eocene porphyry. The extensive lead-silver deposits of Leadville, the iron-zinc deposits of Gilman, the molybdenite deposits of Climax, the lead-silver deposits of Montezuma, Silver Plume, and Georgetown, the gold deposits of Gilpin County and Central City, and the tungsten deposits of Nederland were formed at this time. Although most of the mineralization in the San Juan Mountains occurred in Miocene time, some deposits of Eocene age were formed near the centers of early Tertiary intrusion in that region.

Oligocene.—Light-colored sandstones and marly clays of Oligocene age rest unconformably on the Cretaceous rocks and are unconformably overlain by Miocene beds in northeastern Colorado. Oligocene conglomerates and sandstones rest unconformably upon the early Eocene a short distance south of Denver. No rocks of undoubted Oligocene age have been found in the western half of Colorado, but some of the light-colored marly clays beneath the Miocene sandstones and conglomerates of Middle and North Parks may be Oligocene.

It is probable that some of the post-Eocene volcanic rocks of the San Juan Mountains which are older than lavas of definite Miocene age were formed in the Oligocene epoch. Compared with the volcanism of the Eocene and that of the Miocene, the volcanic activity of the Oligocene was unimportant.

Miocene.—The eastern part of Colorado is covered by later Tertiary sediments, chiefly sand and clay of Miocene and Pliocene age. Miocene sand, gravel, and clay and interstratified

lavas and volcanic débris cover extensive areas in some of the geologic and topographic basins which lie just west of the Front Range and the Sangre de Cristo Range. In northwestern Colorado conglomerate and soft white sandstone of Miocene age overlie Eocene beds unconformably. In the southwestern part of the State Miocene gravel, sand, and clay are interbedded in the thick series of volcanic rocks described in the next paragraph. In the southern part of the Front Range lake beds of Miocene age, such as those that occur at Florissant, are associated with volcanic material.

Miocene volcanism.—Like the late Cretaceous and early Eocene, the Miocene epoch saw widespread volcanic activity in Colorado. The principal volcanic centers of Miocene time are found in the San Juan Mountains, in the southwestern part of the State, but isolated Miocene volcanic centers occur in the southern and northern parts of the Front Range.

Several post-Eocene volcanic series have been found in the San Juan Mountains. Each series includes many different kinds of lavas, several different tuffs and breccias, and, in many places, some sand and clay members. Most of the Miocene lavas and tuffs are andesitic, but rocks ranging in composition from basalt to rhyolite are common, and alkaline rocks such as phonolite occur locally.

Associated with the Miocene volcanic rocks are intrusive porphyritic and granitoid rocks, which commonly range in composition from gabbro to granite but include also lamprophyre and nephelite-syenite. Ore deposits have been found in many of the regions of Miocene intrusive activity and are in most places genetically related to the late Miocene intrusive rocks. The ore deposits of Cripple Creek, in the Front Range, and most of the ore deposits of the San Juan Mountains belong in this class.

Pliocene.—Pliocene clay and sand occur in many places in eastern Colorado but are nowhere abundant. Gravel, sand, and lake deposits of Pliocene age are present in the basin just west of the Sangre de Cristo Mountains, and similar deposits may be present in some of the basins farther north. In the San Juan Mountains some of the late lavas, tuffs, and gravel deposits are probably Pliocene.

Quaternary.—The high mountains of Colorado were glaciated three times during the Pleistocene epoch. The outwash from the early glaciers occurs as high terraces along the intermountain valleys of central Colorado and in the lower stretches of some of the mountain valleys. In a few places morainal deposits of the first glacial stage have been found. The outwash from the late glacial stage has formed the extensive low terraces so

conspicuous along many of the intermountain valleys and in the lower reaches of most of the valleys that head among the high mountains. Some terraces of intermediate position probably represent outwash from a third glacial stage, which has left no other trace in most places, though recorded by till in parts of the San Juan Mountains. In central Colorado well-preserved moraines of the last glacial stage are common above an altitude of 9,000 feet (2,743 meters) in valleys that head among mountains rising more than 11,500 feet (3,505 meters), and in a few of the largest mountain valleys the moraines are found at altitudes as low as 8,500 feet (2,591 meters). Glaciers extended to much lower altitudes in the San Juan Mountains, and extensive moraines of Wisconsin age are found as low as 7,200 feet (2,195 meters).

STRUCTURE

The early topography and geologic structure of Colorado have had a profound influence on the later structural history. The Tertiary folding and faulting were localized or modified by such preexisting features as the Paleozoic highlands and basins.

The ancient highlands that separated the basins of deposition in Paleozoic and Cretaceous time can be outlined with considerable certainty. As shown in Figure 4, there were four major highlands—the Uncompahgre highland in southwestern Colorado, the Front Range highland in central and north-central Colorado, the Wet Mountain highland in south-central Colorado, and the southeastern Colorado highland. The Uncompahgre highland trends northwest; the southern and western part of the wedge-shaped Front Range highland also trends northwest, but its eastern edge runs almost due north; the narrow Wet Mountain highland trends northwest and ends a short distance south of the Front Range highland; and the southeastern Colorado highland lies southeast of the Wet Mountain highland and extends southward into New Mexico.

The largest sedimentary basins in Colorado are (1) the southwestern Colorado basin, lying just southwest of the Uncompahgre highland; (2) the central Colorado basin, lying chiefly between the Uncompahgre highland and the Front Range highland but splitting in the southeastern part and passing on both sides of the Wet Mountain highland; (3) the Denver Basin, lying just east of the central part of the Front Range highland; (4) the Uinta Basin; (5) the Green River Basin. The Uinta and Green River Basins form the northwestern extension of the central Colorado basin. The southwestern Colorado and central Colorado basins developed in Paleozoic

time, but the Denver Basin was unimportant until the Cretaceous period. The Uinta and Green River Basins developed in early Eocene time.

During the Paleozoic era the southwestern Colorado basin and the southern half of the central Colorado basin were deep troughs, and sediment accumulated in them to a thickness of as much as 15,000 feet (4,572 meters). During the later half of Paleozoic time the central Colorado basin was broken by an uplift, which joined the north end of the Wet Mountain highland with the

FIGURE 4.—Structural elements of Colorado, showing the chief sedimentary basins and ancient highlands

Front Range highland, but a deep basin of deposition bordered the west side of these joined highlands. It is possible that the Wet Mountain highland extended continuously down to the southeastern Colorado highland in late Paleozoic time, but this has not yet been proved. The accumulation of the thick sediments involved the downwarping of the troughs and the uplift of the adjacent highlands. The dominant trend of these embryonic folds in Paleozoic time was northwest. During the Upper Cretaceous epoch the whole State was submerged, but by far the thickest sediments accumulated in the Denver Basin just

east of the present Front Range, in the northeastern quarter of the State.

Most of the pronounced structural features of Colorado were formed in early Tertiary time. The most intense folding occurred at the edges or near the centers of the deepest basins of deposition. In all except the northwestern part of the State the dominant trend of the early Eocene folds and faults is northwest.

On the east side of the Front Range, bordering the deep Cretaceous basin, is an échelon arrangement of the northwestward-trending folds, resulting in a north-south mountain range. Strong steep reverse faults and locally overturned beds are common on the edge of the Denver Basin between Denver and Boulder. Farther north the échelon northwest folds are asymmetric, with the steep side toward the west. Many of the échelon folds are broken by faults that drop the west side. The Ute Pass fault, near Colorado Springs, a persistent northwesterly fault of this type, can be traced northwestward for 30 miles (48 kilometers) by a downthrown block of sediments in the pre-Cambrian area.

The most prominent structural features of the west side of the Front Range are the series of great northwestward-trending faults which are common in the region east of Leadville. In all the major faults of this type the downthrown side lies on the west. Some of them are normal faults, some are steeply dipping reverse faults, and a few are gently dipping thrust faults. The easternmost of the major faults is the Williams Range thrust fault, which forms the western limit of the Front Range for more than 50 miles (80 kilometers). (See pl. 3.) This fault has a horizontal displacement of more than 4½ miles (7.2 kilometers). (See p. 104.) In this part of Colorado the belt of northwesterly faulting coincides with the northeastern edge of the central Colorado basin, but farther south the belt splits around the Wet Mountain highland. The folding and thrust faulting on the north side of the Wet Mountains gradually dies out to the southeast.

The folding that was localized along the western edge of the Front Range highland was not as intense along the southwestern edge of the Wet Mountain highland as it was a few miles farther west, near the center of the Carboniferous basin. There the thick series of red grits and sandstones have been buckled into sharp isoclinal folds, cut by many thrust faults and normal faults. This complicated structural element is contained in the northwestward-trending Sangre de Cristo Mountains of south-central Colorado. At the north end of the mountains some folds and faults swing north and others swing west, following the northeastern edge of the Uncompahgre highland.

The westerly swing of the Sangre de Cristo structure continues for about 50 miles (80 kilometers), to the Gunnison region, where it gives way to a northwesterly arrangement of échelon folds and faults that continues north nearly to Glenwood Springs. The major folds and faults of this belt are found between the Gunnison River and the Frying Pan River. The folds are similar to those of the Front Range, trending northwest and having overturned limbs on the southwest side of the anticlinal axes. Where these regional folds are broken by thrust faults or normal faults, the downthrown side lies on the southwest.

In the region of the Tertiary beds west of Glenwood Springs the synclinal structure of the central Colorado sedimentary basin has been little broken by folds and faults. Just north of Glenwood Springs a broad regional anticline brings pre-Cambrian rocks to the surface in the deeper valleys near the center of the uplift. East-west faults are common on the south side of the uplift, and in most of them the downthrown side is on the south. This uplift can be followed northwest to the Yampa River, where it swings west near Juniper Mountain and continues in a west-northwest direction to the Utah line, passing out of Colorado a short distance south of the northwest corner of the State.

In that portion of the uplift north of the Yampa River the northeast side is marked by a zone of faults that trend west or northwest. The faults in the northwestern part of this zone have their downthrown sides on the north, but the throw is much less than formerly, and it is probable that the downthrown side has moved up several thousand feet. In the southeastern part of the belt the reversed movement is all that is evident, and the downthrown side along these faults lies on the south or southwest. These faults, in common with most of the others in the northwestern part of the State, are influenced by the Uinta Mountain anticline in Utah, a short distance farther west. This anticline trends nearly east-west, and pre-Cambrian rocks are exposed in its center for more than 150 miles (241 kilometers).

The western and southern limits of the regional syncline that lies west of Glenwood Springs coincides approximately with the valley of the Gunnison River and that part of the Colorado River lying below the mouth of the Gunnison. West of the northwesterly part of the lower Gunnison River in the Uncompahgre Plateau is a broad regional anticline in which pre-Cambrian rocks are exposed in the valleys near its center. The general trend of this uplift is northwest. The anticlinal structure of the uplift becomes less and less evident to the south, where the dominant structure is that of narrow northwestward-trending folds and fault blocks. Some of the anticlines have broken close to their axes, and the crest has dropped in, forming a

narrow downthrown fault block. Gently flexed, unbroken northwesterly folds are also common. Several prominent northwestward-trending faults occur east of the Dolores and San Miguel Rivers, and in almost every one the downthrown side is on the southwest. However, the regional structure between the San Miguel and Gunnison Rivers is almost monoclinal.

Where the Gunnison River changes its westerly course and flows northwest through the Black Canyon, about 15 miles (24 kilometers) east of Montrose, the river parallels or follows the course of a prominent northwesterly fault for 25 miles (40 kilometers). This fault has a displacement of several thousand feet, and its downthrown side lies on the southwest.

The San Juan Mountains are a broad, kite-shaped uplift lying south of the Gunnison River and west of the San Luis Valley. The long axis runs northwest from the New Mexico line to the Black Canyon. The uplift flares out abruptly southeast of the Black Canyon to its greatest width, which is found along a northeasterly line extending from Rico toward Salida. Southeast of this line the uplift tapers gradually to a narrow inconspicuous mass a short distance south of the New Mexico boundary.

The structure of the San Juan Mountains is the result of several epochs of diastrophism. In a general way the San Juan Mountains correspond to the southern part of the Paleozoic Uncompahgre highland. Marked folding occurred along the southern edge of the highland in Triassic time and gave rise to a series of northwesterly folds, which were beveled before the deposition of Jurassic sediments. In the central part of the uplift, however, all the pre-Tertiary rocks are covered by Tertiary lavas, and the early structure is effectually hidden.

A northerly and northeasterly warping is conspicuous along the west side of the San Juan Mountains. This folding began in late Cretaceous time and was accompanied by intrusive and extrusive activity. The folding continued well into the Eocene and extended from the southwest corner of Colorado across the San Juan Mountains and the Front Range to the northeastern part of the State. From the San Juan Mountains to the east-central part of the Front Range this line of folding is marked by many stocks and sills of Eocene quartz diorite and quartz monzonite porphyry. (See pls. 1 and 4.) In the plains northeast of Boulder it is marked by many northeasterly faults and by a broad northeastward-plunging fold that passes across the Platte Valley a short distance east of Greeley and continues on toward Wyoming. It seems probable that much of the northeasterly structure is related to the porphyries that are alined along the folds. The intrusion of the stocks was soon followed by a widespread mineralization in the so-called porphyry belt,

which gave rise to many of the most noted ore deposits in Colorado. The ores of many important mining districts, including Gilman, Red Cliff, Leadville, Breckenridge, Alma, Silver Plume, Georgetown, Idaho Springs, Central City, Nederland, Aspen, and a few of the deposits in the San Juan Mountains, were formed at this time.

After the early Eocene mineralization there was little structural change in Colorado until the end of the Eocene epoch. By that time most of the mountain areas had been reduced to nearly level or gently undulating surfaces. During the Miocene epoch there were widespread uplifts of the chief mountain areas in the State. The streams again became active along the borders of the mountains and gradually beveled a new low-level surface which worked slowly toward the center of the uplift. It is probable that much of the Miocene uplift took place by renewed movement along faults and through regional arching of the mountain ranges.

During Miocene time many stocks of porphyritic rock were intruded and large amounts of lava ranging from basalt to rhyolite were extruded. Many ore deposits are associated with the Miocene intrusive rocks. The gold and silver veins and gold and silver bearing base-metal deposits of the San Juan Mountains are of this age. In some of the volcanic vents important ore deposits were formed. The most noteworthy of these were the gold-telluride deposits at Cripple Creek, and the silver deposits of Silver Cliff and the Rosita Hills. The Miocene lavas of the Front Range are little disturbed and are nearly horizontal, but those of the San Juan Mountains are much faulted and tilted at many places.

Much of the uplift of the San Juan Mountains along their eastern border was accomplished by faulting in the Miocene, Pliocene, and Pleistocene epochs, during which the San Luis Valley region moved down while the San Juan Mountains moved up. The east side of the valley, which borders the Sangre de Cristo Mountains, probably has a similar history. Some north-northeasterly faults near the east side of Middle Park are probably of Miocene age, but in general the Miocene volcanic activity in this region was not accompanied by conspicuous faulting, folding, or uplift.

At the end of the Pliocene or early in Pleistocene time the mountainous areas in Colorado were again uplifted, in part by faulting and in part by regional arching. The elevated Miocene surfaces were soon trenched by the streams near the borders of the mountains and were deeply cut by glaciers near the mountain crests, but in many of the ranges there still remains a strip of rolling upland between the rugged glaciated centers

of the range and the canyon-cut outer borders. This upland preserves the topography of the Miocene and Pliocene surfaces, only slightly modified by Pleistocene erosion. Since the last Pleistocene glaciation many streams have cut small canyons in the bedrocks of the mountains, but in general there is little evidence of recent uplift.

GENERAL BIBLIOGRAPHY

[Exclusive of the references given for excursions 1, 2, and 3]

1. Beekly, A. L., Geology and coal resources of North Park, Colorado: U. S. Geol. Survey Bull. 596, 1915. Geologic map; stratigraphy and structure of this part of central northern Colorado.

2. Butler, B. S., Relation of the ore deposits of the southern Rocky Mountain region to the Colorado Plateau: Colorado Sci. Soc. Proc., vol. 12, pp. 23–36, 1929. A general paper on the regional aspects of the ore deposits of Colorado, Utah, Nevada, Arizona, and New Mexico.

3. Campbell, M. R., Guidebook of the western United States, Part E, The Denver & Rio Grande Western Route: U. S. Geol. Survey Bull. 707, 1922. A popular account of the geology along this railroad.

4. Chamberlin, R. T., The building of the Colorado Rockies: Jour. Geology, vol. 27, pp. 145–164, 225–251, 1919. Summarizes literature on stratigraphic relations in the region containing the Front Range, the Wet Mountains, the Park Range, the Sangre de Cristo Range, and the Sawatch Range. Gives a geologic section across the mountains from a point near Boulder to one a short distance west of Glenwood Springs and estimates the crustal shortening involved in the mountain building.

5. Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 365–388, 1924. General paper on the porphyries of the early Eocene "mineral belt" of Colorado.

6. Darton, N. H., The geology and underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Prof. Paper 52, 1906. The reconnaissance geology of much of central eastern Colorado. Includes a geologic map.

7. Darton, N. H., Guidebook of the western United States, Part C, The Santa Fe Route: U. S. Geol. Survey Bull. 613, 1915. A popular account of the geology along this railroad.

8. Hancock, E. T., and Eby, J. B., Geology and coal resources of the Meeker quadrangle, Colorado: U. S. Geol. Survey Bull. 812, pp. 191–242, 1929. Geologic map and text describing the stratigraphy and structure of a typical area of northwestern central Colorado.

9. Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, 1926. A history of the discovery, development, and production of the metalliferous mines of Colorado.

10. Heaton, R. L., Relation of accumulation to structure in northwestern Colorado: Typical American oil fields, vol. 2, pp. 93–114, Am. Assoc. Petroleum Geologists, 1929. Describes briefly the productive oil structures of northwestern Colorado and their stratigraphy.

11. Hunter, J. F., Pre-Cambrian rocks of the Gunnison River, Colorado: U. S. Geol. Survey Bull. 777, 1925. Description of the pre-Cambrian rocks and their relations and structure in the western part of the San Juan Mountains region.

12. Johnson, J. H., Contribution to the geology of the Sangre de Cristo Mountains of Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 2–21, 1929. A general paper on the stratigraphy of this mountain range.

13. Kirk, Edwin, The Harding sandstone of Colorado: Am. Jour. Sci., 5th ser., vol. 20, pp. 456–465, 1930. Summarizes evidence proving the Ordovician age of the Harding sandstone, which contains fish remains.

14. Kirk, Edwin, The Devonian of Colorado: Am. Jour. Sci., 5th ser., vol. 22, pp. 220–240, 1931. Discusses confusion of earlier correlations of pre-Pennsylvanian formations in Colorado and gives reasons for the revision which has been adopted by the U. S. Geological Survey, corresponding to the usage followed in the guidebook.

15. Knowlton, F. H., The Laramie flora of the Denver Basin, with a review of the Laramie problem: U. S. Geol. Survey Prof. Paper 130, 1922. Discusses the paleobotany of the Laramie formation of eastern Colorado and gives the evidence for placing the boundary between Cretaceous and Eocene at the end of the Laramie epoch instead of at the end of the Denver epoch. For contrary views see Stanton (22).

16. Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colorado: U. S. Geol. Survey Bull. 510, 1912. Geologic map and text describing the stratigraphy and general geology of a typical area of southwestern central Colorado.

17. Lee, W. T., Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U. S. Geol. Survey Prof. Paper 149, 1927. Descriptions and sections of the Paleozoic and part of the Mesozoic sediments on the east side of the Front Range.

18. Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, 1917. Reconnaissance and detailed geology of a large area along the eastern edge of the Sangre de Cristo and Wet Mountains in central southern Colorado.

19. Roth, Robert, Regional extent of the Marmaton and Cherokee Mid-Continent Pennsylvanian formations: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 1249–1278, 1930. Correlates certain Pennsylvanian beds in Kansas and Oklahoma with those of central Colorado and eastern Wyoming on paleontologic evidence.

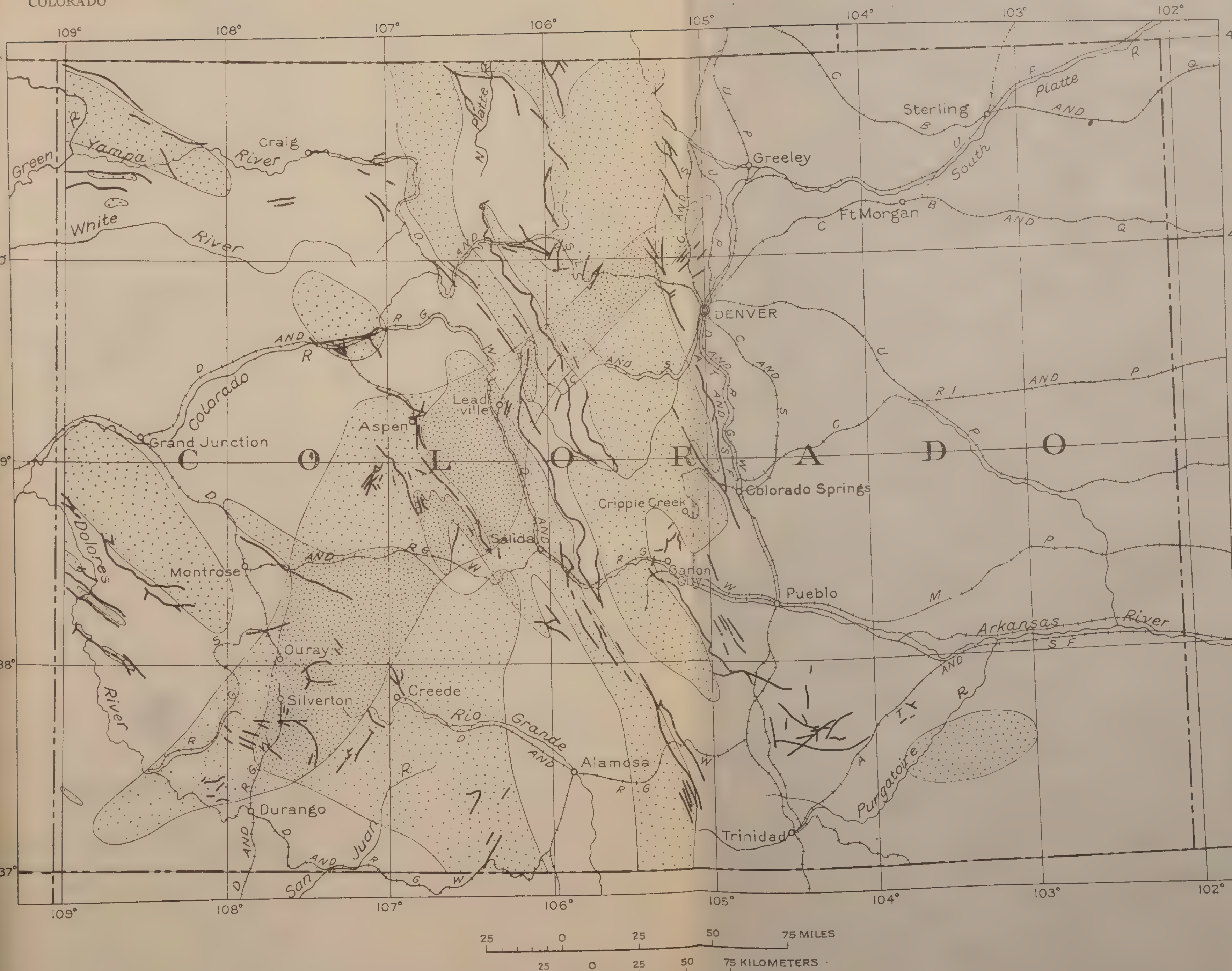
20. Sears, J. D., Geology and oil and gas prospects of part of Moffat County, Colorado, and southern Sweetwater County, Wyoming: U. S. Geol. Survey Bull. 751, pp. 269–320, 1924. Describes the stratigraphy and structure of much of northwestern Colorado.

21. Sears, J. D., and Bradley, W. H., Relations of the Wasatch and Green River formations in northwestern Colorado and southern Wyoming, with notes on oil shale in the Green River formation: U. S. Geol. Survey Prof. Paper 132, pp. 92–107, 1925.

22. Stanton, T. W., Boundary between Cretaceous and Tertiary in North America as indicated by stratigraphy and invertebrate faunas: Geol. Soc. America Bull., vol. 25, pp. 341–354, 1914. Gives reasons for believing that the boundary between the Cretaceous and Tertiary should be placed after the Denver epoch. For contrary views see Knowlton (15).

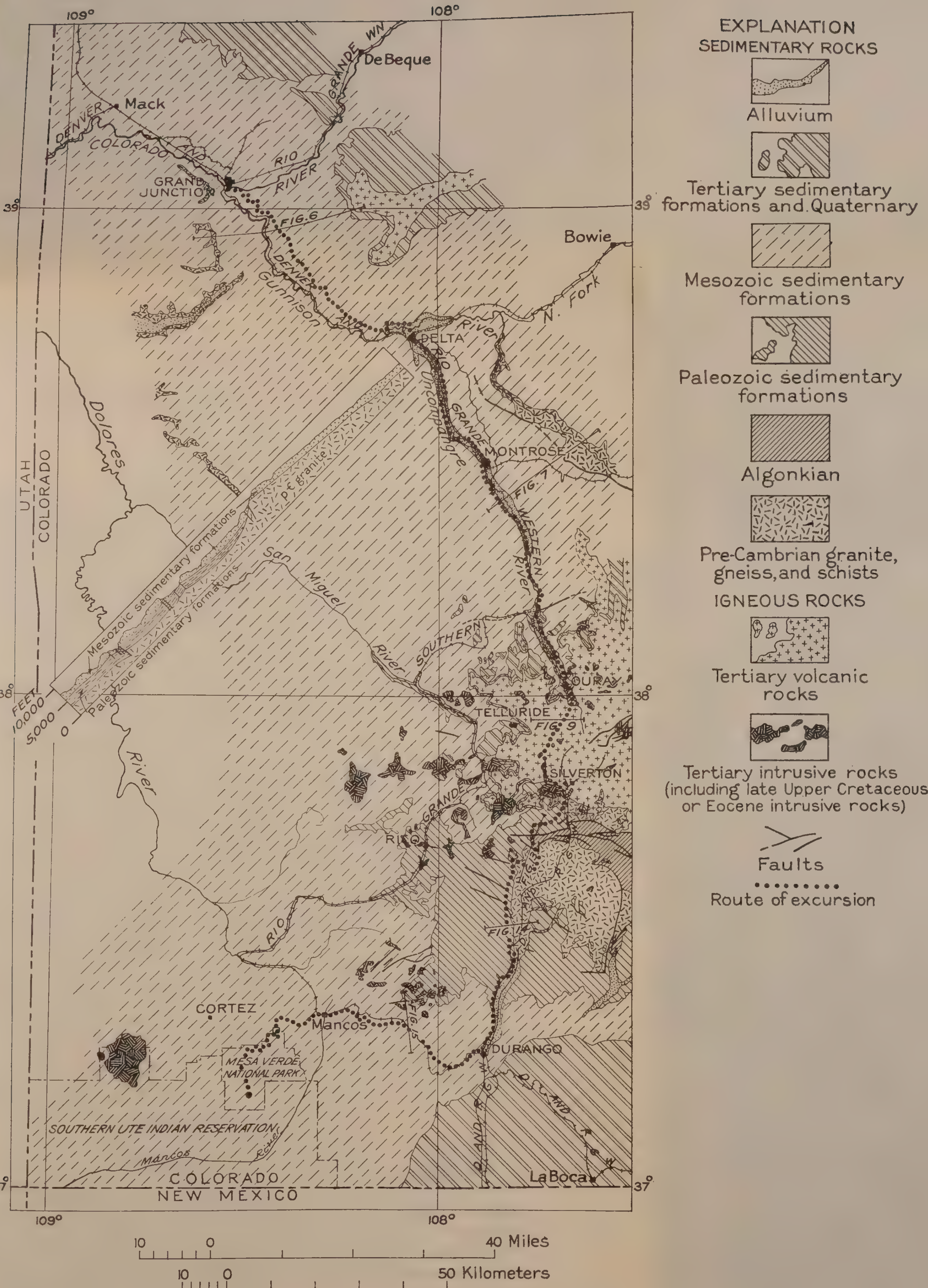
23. State Historical and Natural History Society of Colorado, History of Colorado, 1320 pp., Denver, 1927.

24. Winchester, D. E., Oil shale of the Rocky Mountain region, Colo.: U. S. Geol. Survey Bull. 729, 1923. Summarizes occurrence and stratigraphy of the Tertiary oil shale of western and northwestern Colorado.



PRINCIPAL FAULTS AND AREAS OF EARLY TERTIARY UPLIFT IN COLORADO

The uplifts are stippled; where one uplift crosses another the stippling is denser. The northeastward-trending uplift includes the "porphyry belt" of Colorado, the region in which the late Cretaceous and Eocene(?) intrusive rocks are abundant.



GENERALIZED GEOLOGIC MAP AND SECTION SHOWING ROUTE OF EXCURSION IN SOUTHWESTERN COLORADO

GRAND JUNCTION TO MESA VERDE

By W. S. Burbank

INTRODUCTION

The first part of excursion 1, between Grand Junction and Montrose, lies within the Colorado Plateau province, close to the western front of the ranges comprising the southern Rocky Mountains. Between Montrose and Ouray the route enters the western San Juan Mountains, formed by the dissection of a part of the great Tertiary volcanic plateau of southern Colorado and northern New Mexico, the volcanic eruptions of which must have originally covered an area of not less than 15,000 square miles (38,850 square kilometers). The San Juan Mountains proper cover an area of a little over 3,000 square miles (7,770 square kilometers). The extreme relief of 6,000 feet (1,829 meters) in these mountains affords an unusually complete section of the geologic formations and their structural history from pre-Cambrian to Tertiary.

Between Silverton and Durango the excursion leaves the area of volcanic rocks and passes through the western part of the Needle Mountains, a quaquaversal uplift affecting rocks ranging from Archean to Mesozoic in age. From Durango to Mesa Verde the route skirts the southern edge of the La Plata Mountains, a late Cretaceous or early Tertiary laccolithic dome with complex igneous intrusions, on the western flank of the main San Juan dome. This part of the route also follows the northern rim of the San Juan Basin of Colorado and New Mexico, noteworthy for its record of the late Cretaceous and Tertiary sedimentation.

Plate 4 and Figure 5 show the geology and main physiographic features along the route and in adjacent areas. The return trip from Mesa Verde is to be made over the same route.

[Note.—The general descriptive matter should be read by members of the excursion before the first day's trip, which will probably cover the route between Grand Junction and Ouray.]

COLORADO PLATEAU REGION

GEOGRAPHY AND GENERAL GEOLOGY

Grand Junction, the starting point of the excursion, lies in the broad valley of the Colorado River near its junction with the Gunnison River. Near the margin of the plateau region these rivers have eroded wide valleys, in contrast to the deep and relatively narrow canyons typical of the Colorado Plateau farther south and west. The flood plains and silt-covered ter-

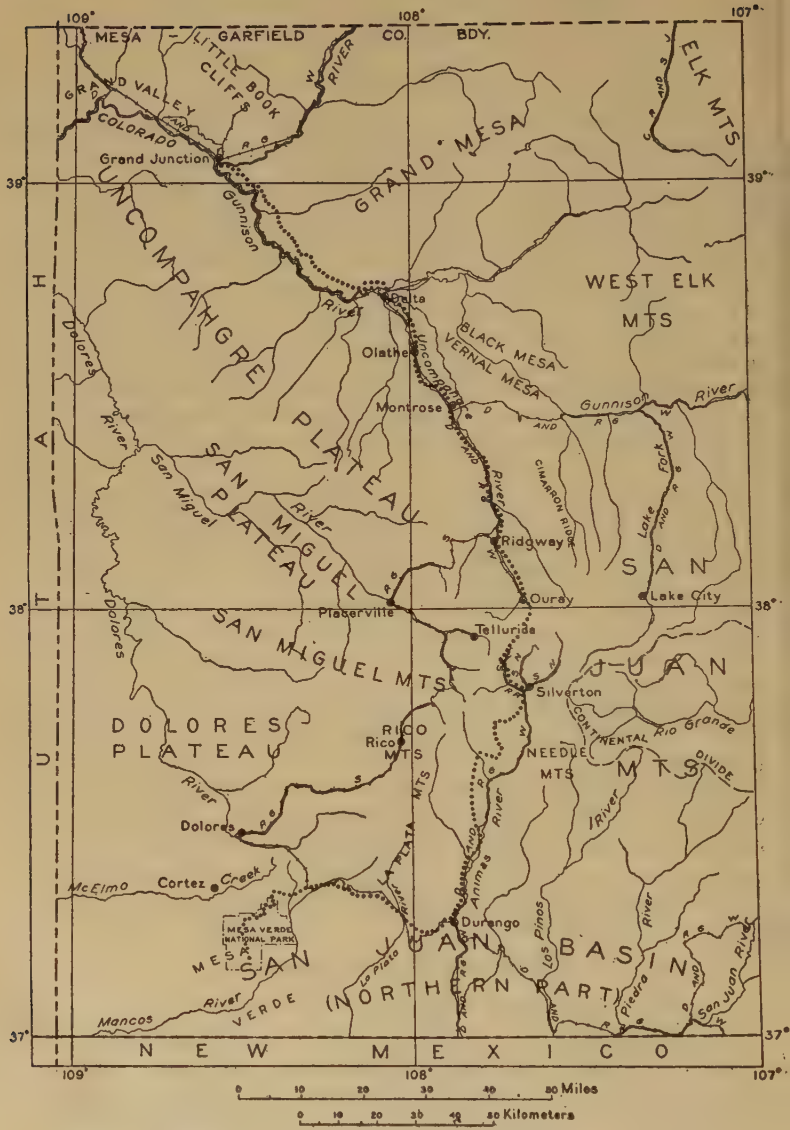


FIGURE 5.—Principal physiographic features of southwestern Colorado

Geologic formations of the Plateau province, vicinity of Grand Junction and Delta

System	Series	Formation	Character	Thickness	
				Feet	Meters
Quaternary.	Recent.		Gravel, sand, and silt.		
	Pleistocene.		Terrace gravel, etc.		
Tertiary.	Pliocene (?) or Miocene (?).		Basaltic lava and tuff.	50–400	15–122
	—Unconformity—				
	Eocene.	Green River formation.	White friable sandstone and clay shale.	200–1,800	61–549
		Wasatch formation.	Conglomeratic sandstone, fine-grained sandstone, and shale, varicolored.	500–2,500	152–762
	—Unconformity—				
Cretaceous.	Upper Cretaceous.	Mesaverde formation.	At base, white cliff-making sandstone containing fucoids and marine invertebrates. Above, dark shale, coal-bearing beds, and sandstones, containing plant remains and fresh-water invertebrates. (At top, some beds of Tertiary (?) age have been included in the mapping.)	1,600–2,500	488–762
		Mancos shale.	Chiefly dark shale, somewhat carbonaceous near the base, with a few sandy shales, sandstones, and thin limestones. Contains marine invertebrates, showing the lower portion to be of Benton age, the middle portion of Niobrara age, and the upper portion of Pierre age, but there are no well-defined lithologic divisions.	3,000–5,700	914–1,737
		Dakota (?) sandstone.	At base, conglomeratic sandstone, with pebbles of quartzite, chert, and shale. Overlain by alternate layers of sandstone, carbonaceous shale, and coal.	80–150	24–46
	—Unconformity—				
Cretaceous (?).	Lower Cretaceous (?).	Morrison formation.	Lower part, cross-bedded sandstones, shales, and thin limestones. Middle part, shales and sandstones, colored in various shades of red, green, yellow, and gray. Upper part, conglomeratic sandstone, with some variegated shale. Fresh-water invertebrates are found in limestones of the lower part.	650–700	198–213
Jurassic and Jurassic (?).		(Undivided.)	Massive and in part highly cross-bedded maroon sandstone. Along Gunnison Valley below Delta is a fine to medium grained sandstone composed of white quartz sand cemented by iron oxide. Unfossiliferous.	150–200	46–61
	—Unconformity—				
Triassic.	Upper Triassic.	Chinle formation.	Sandstones, shales, and conglomeratic beds, chiefly of bright-red or red-brown colors.	50–70 ?	15–21
	—Unconformity—				
Pre-Cambrian.			Chiefly granite but includes some schist or gneiss.		

races of the Colorado, Gunnison, and Uncompahgre Rivers in Colorado support an important agricultural industry. Because of the semiarid climate on the plateau west of the mountains agriculture is dependent on irrigation.

Near Grand Junction the valley of the Colorado has been eroded in soft marine shales of Cretaceous age and is bounded on the northeast by the Book Cliffs, an escarpment formed by the harder sandstones and shales of the overlying coal-bearing Cretaceous (Mesaverde group). The beds in this escarpment dip northeastward beneath the Book Plateau, a part of the Uinta Basin of Tertiary sedimentation in Colorado and Utah. Overlying the Upper Cretaceous in this basin are thick deposits of Tertiary age, chiefly comprising the Wasatch, Green River, and Bridger formations. The basin contains gas and oil pools and extensive deposits of oil shale of potential importance.

The Grand Mesa, which forms the main topographic feature east of the Colorado and Gunnison Valleys near Grand Junction, is an outlier of the Uinta Basin formations cut off from them by the valley of the Colorado River. The capping of this mesa is composed of late Tertiary basalt flows and is underlain by the Green River and Wasatch formations (Eocene).

The north end of the Uncompahgre Plateau constitutes the prominent upland southwest of Grand Junction and west of the Gunnison Valley. This is a broad anticlinal segment of the Colorado Plateau, of northwesterly trend. It is composed of a comparatively thin blanket of Triassic, Jurassic, and Cretaceous formations lying upon the pre-Cambrian granite. The Uncompahgre Plateau extends southeastward from the Colorado River to the San Juan Mountains and has a total length of nearly 100 miles (161 kilometers) and a width of 20 to 30 miles (32 to 48 kilometers), with its summit altitudes ranging between 9,000 and 10,000 feet (2,743 and 3,048 meters) above sea level. This plateau is bounded on the east by the valleys of the Uncompahgre and Gunnison Rivers and on the west by the San Miguel and Dolores Rivers. The route of the excursion between Grand Junction and Montrose parallels the eastern boundary of this large unit of the Colorado Plateau. East of the excursion route and south of Grand Mesa there are several minor positive units of the plateau, which border the western front of the southern Rocky Mountains.

STRATIGRAPHY

The geologic formations of the plateau along the route of the excursion between Grand Junction and Montrose are listed in the accompanying table.

STRUCTURE

The main features of the geologic structure of the eastern part of the Colorado Plateau are a series of broad anticlinal uplifts with intervening synclines of prevailing northwesterly trend. In Colorado close to the mountain front the uplifts are slightly warped segments with gentle eastward dip bounded by sharp monoclinal flexures and faults on the western flanks and by more gentle monoclinal flexures on the eastern flanks. This eastward dip of the positive elements is well illustrated by the Uncompahgre Plateau, Mesa Inclinada (Black Mesa), and Vernal Mesa with the shallow intervening syncline of the Uncompahgre River Valley. (See fig. 7 and section, pl. 4.) Toward the north near Grand Junction the eastern escarpment of the Uncompahgre Plateau is, however, marked by a more abrupt upturning of the formations. North of Delta the syncline of the Uncompahgre Valley coalesces with the southeastern portion of the Uinta Basin, and the older formations are not again exposed to the east until they are upturned against the flank of the Elk Mountains, about 75 miles (121 kilometers) east of Grand Junction.

Farther south, in the San Miguel and Dolores Plateaus, the structure is less well known but comprises in the main broad regular anticlines and synclines, only here and there broken by monoclinal flexures and local domes. The San Miguel Mountains, which lie between these plateaus, are geologically a spur of the San Juan Mountains isolated by erosion, and their structure is dominated by a number of large intrusive bodies of dioritic and monzonitic composition. In the western part of the Dolores Plateau the surface rock is chiefly the Dakota (?) sandstone, but toward the east, near the San Miguel Mountains, the overlying Mancos shale has not been eroded.

An area of comparatively complex structure within the plateau province in Colorado is found west of the Uncompahgre Plateau in the northern part of the drainage basins of the Dolores and San Miguel Rivers. Here the plateau formations are deformed by closely spaced anticlines, synclines, and quaquaversal folds, and the anticlines are modified by numerous strike faults and some cross faults. Gypsum beds, probably of Pennsylvanian age, are involved in some of the uplifts and have intrusive or other tectonic relations to the younger beds. Although these anticlines parallel the Uncompahgre plateau, they are younger than the Pennsylvanian, Permian, and Lower Triassic land mass of which the northern portion of the Uncompahgre Plateau is composed. The cross section on Plate 4 gives a general picture of the structure across this part of the Colorado Plateau, illustrating diagrammatically the overlap of the Upper Triassic and Jurassic beds on the old land mass of the Uncompahgre

uplift. For more details of the interesting structure of this region the reader should consult the publication by Coffin (8) given in the bibliography (p. 65). This region is also well known for its deposits of vanadium and uranium, which have been described by Coffin.

A few isolated laccolithic mountain uplifts break the typical plateau structure in southwestern Colorado and eastern Utah, among which are the Ute Peak, near Mesa Verde, and the La Sal and Abajo Mountains of eastern Utah. These mountains, on clear days, are visible from Mesa Verde.

ROAD LOG

From Grand Junction (altitude 4,608 feet, or 1,404 meters), the highway to Delta crosses the Colorado River southward and turns to the east onto a late Pleistocene gravel-covered terrace deposited on the Upper Cretaceous Mancos shale, about 60 to 70 feet (18 to 21 meters) above the river flood plain.

1.6 (2.6).[5] From this first terrace level on the south side of the river a good view is obtained of the Book Cliffs, the Grand Mesa, and the northeastern escarpment of the Uncompahgre Plateau on which are exposed the upturned Triassic and Jurassic red beds. The road continues east and south, partly along the same terrace level, and gradually rises away from the Colorado Valley until at a point about 7 miles (11.3 kilometers) out of Grand Junction it turns east onto a remnant of a higher Pleistocene gravel-covered terrace about 350 feet (107 meters) above the Colorado River. This terrace and the near-by mesas are underlain by Mancos shale.

8 (12.9). The road turns south and goes down from the high gravel plain, winding through hills of Mancos shale to a low plain bordering the Gunnison River at the town of Whitewater, 10.8 miles (17.4 kilometers) from Grand Junction. The road continues southeastward out of Whitewater roughly parallel to the course of the Gunnison River, which lies to the west (right) of the road, in a canyon behind an escarpment of the Dakota (?) sandstone (basal Upper Cretaceous.) A cross section showing the geologic structure from Grand Mesa to the Uncompahgre Plateau near Whitewater is given in Figure 6. For over 20 miles (32 kilometers) beyond Whitewater the route follows closely the contact between the Dakota (?) sandstone and Mancos shale, east of the Dakota (?) cuesta.

16 (25.7). Just beyond Kahnah Creek the road climbs several terraced levels that are covered with heavy boulder beds com-

---

[5] Figures show distance from Grand Junction in miles, with kilometers in parentheses.

FIGURE 6.—Geologic section from Grand Mesa across the Gunnison River near Whitewater to the Uncompahgre Plateau. Tb, Tertiary basalt; Tgr, Green River formation (Eocene); Tw, Wasatch formation (Eocene); Kmv, Mesaverde formation (Upper Cretaceous); Kmc, Mancos shale (Upper Cretaceous); Kd, Dakota (?) sandstone (Upper Cretaceous); Km, Morrison formation (Lower Cretaceous?); ƦJ, Triassic and Jurassic rocks, undivided; Ag, chiefly granite with some schist and gneiss (pre-Cambrian)

posed of basaltic lava of the kind capping Grand Mesa. These gravel-capped mesas are remnants of the gentle valley slopes that bordered the Gunnison River in Pleistocene time. The road continues southeastward along the level of the older valleys, partly in Mancos shale and partly along the upper part of the Dakota (?) sandstone. From certain points along the road a distant view of the San Juan Mountains can be obtained on clear days.

27.8 (44.7). Just before reaching a small side canyon that enters the Gunnison River at Dominguez, exposures of the carbonaceous shales and sandstones of the Dakota (?) formation are seen at the left in a road cut. Below on the right the upper massive conglomeratic sandstones of the Morrison (Cretaceous?) formation are exposed in the canyon walls beneath the Dakota (?) and a distant view is obtained of the Gunnison Canyon, the lower walls of which are composed of pink and maroon sandstones of Jurassic (?) age.

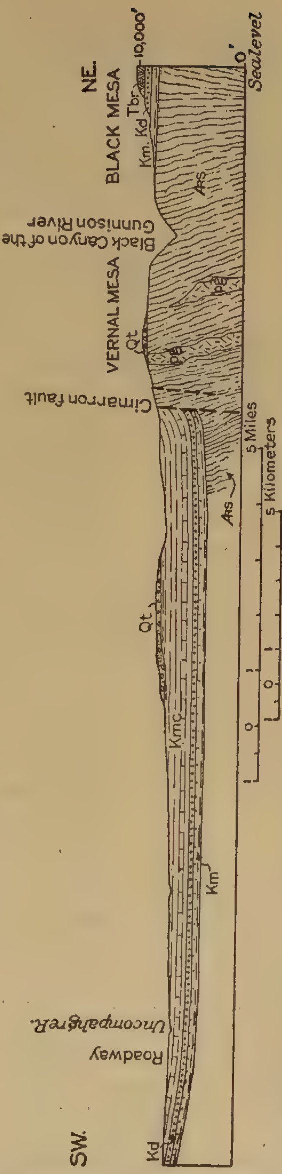
From this point for several miles the road continues southeastward, mostly on the Mancos shale, and excellent views are obtained of the gravel-covered mesas, underlain by Mancos shale, which slope from Grand Mesa down toward the Gunnison Valley. At 32 miles (51.5 kilometers) from Grand Junction the West Elk Mountains, composed of volcanic rocks and older laccolithic intrusive bodies of monzonitic rocks in the Cretaceous formations, are visible to the east in the distance.

37 (59.5). Approaching the town of Delta, at the junction of the Gunnison and Uncompahgre Rivers, the road goes down onto low, partly dissected silt plains bordering the river, and at 43.6 miles (70.2

kilometers) it crosses the Gunnison River into Delta (altitude 4,980 feet, or 1,518 meters).

From Delta to Montrose the route follows the main highway up the broad valley of the Uncompahgre River. This road is chiefly either on the late Pleistocene valley deposits or at the edge of the Recent flood-plain deposits of the river.

47.9 (77.1). Southeast of Delta, Vernal Mesa and Mesa Inclinada (Black Mesa), northeastward-dipping segments of the plateau structure, are seen to the southeast of the road at a distance of 15 to 20 miles (24 to 32 kilometers). The Uncompahgre Valley from Delta to Montrose lies in the trough of a broad syncline of the plateau, between the Uncompahgre uplift on the west and the Vernal and Black Mesa uplift on the east. These mesas, the western escarpments of which are determined by faults and sharp monoclinal flexures of the formations, are composed of pre-Cambrian schists and granites capped by thin layers of Triassic, Jurassic, and Cretaceous sedimentary rocks. The formations on the tops of the mesas dip gently eastward beneath the volcanic rocks of the West Elk Mountains. A structural section from Vernal Mesa across the Uncompahgre Valley near Montrose is shown in Figure 7, and this structure continues in a general way for the entire distance between Delta and Montrose. The Uncompahgre Valley itself is underlain by the Mancos shale (Upper Cretaceous), and outcrops of it are seen at a number of places near the road.



Qt, Cerro till, Tbr, Tertiary volcanic breccia, Kmc, Mancos shale, Kd, Dakota(?) sandstone; Km, Morrison formation; Ars, Archean schist; pg, pegmatite.

FIGURE 7.—Geologic section from Black Mesa southwest across the Uncompahgre River above Montrose

After turning east and crossing the Uncompahgre River at 65.3 miles (105.1 kilometers) the road crosses to the other side of the valley and turns southward toward Montrose. Along this part of the road there is a distant view of the fault scarp at the edge of Vernal Mesa, about 14 miles (22.5 kilometers) to the east. Montrose (altitude 5,800 feet, or 1,768 meters) is reached 67.7 miles (108.9 kilometers) from Grand Junction.

(Road log continued on p. 38.)

THE WESTERN SAN JUAN MOUNTAINS

GEOMORPHOLOGY AND GENERAL GEOLOGY

The western escarpment of the San Juan Mountains as seen from the vicinity of Montrose rises abruptly above the Colorado Plateau to altitudes ranging from 11,000 to over 14,000 feet (3,350 to 4,300 meters). For some distance east of Montrose the plateau formations and structure continue and are partly buried beneath the Tertiary volcanic rocks of the mountains. Two prominent spurs of the San Juan Mountains in this region are the Cimarron Ridge, lying east of the Uncompahgre Valley, and the Sneffels Peak group, which forms the spur between the Uncompahgre and Dolores River drainage basins, to the southwest. The north end of the Cimarron Ridge (Storm King, altitude 11,388 feet, or 3,471 meters) is underlain by the nearly horizontal Upper Cretaceous formations of the plateau region, the Mancos shale and the Mesaverde formation, but its cap is composed of the San Juan tuff, which constitutes the first eruptions of the Tertiary volcanoes. The Sneffels Peak group is also composed of horizontal volcanic formations overlying the Mancos shale, although Sneffels Peak itself (14,158 feet, or 4,315 meters) is composed of intrusive rock. On the flanks of Cimarron Ridge and the crest of Horsefly Peak (10,338 feet, or 3,151 meters), which lies south of the Uncompahgre River between Montrose and Sneffels Peak, there are deposits of the Cerro till, representing the oldest glacial stage of the Pleistocene in the San Juan Mountains. From the position of these oldest till deposits on the interstream divides at each side of the Uncompahgre Valley the great amount of erosion that has occurred since the earliest glaciation becomes strikingly evident. In the valley of the Uncompahgre River there are to be seen numerous terraces that indicate the several stages at which the cycles of erosion were arrested.

Near Montrose four conspicuous levels can be differentiated, the highest of which is equivalent to the outwash from the Cerro glaciers, while those below correspond respectively to the Durango glacial stage, the post-Durango and pre-Wisconsin interglacial stage, and the Wisconsin glacial stage. The lowest

terrace consists of outwash gravel which, near Montrose, is only 20 to 30 feet (6 to 9 meters) above the modern alluvium.

The Durango glaciers, like those of the Wisconsin stage, were of the valley type, but commonly the glaciers were longer, and their morainal deposits are found on the valley slopes just above the present streams and farther down the valley than the Wisconsin till. The outwash of the Durango glaciers caps the rock benches in the Uncompahgre Valley 300 to 500 feet (91 to 152 meters) above the streams.

The Cerro glaciers were much more extensive than those of the two later stages, and during this stage much of the mountain country was covered with an ice cap, while piedmont glaciers and broad valley glaciers spread beyond the mountain front onto the surrounding plateau. The valley deepening in the mountains since this earliest glacial stage has amounted to several thousand feet, and accordingly it has been pointed out by Atwood and Mather (1) that the physiographic development of the great scenic features of the San Juan area is therefore largely the work of interglacial and postglacial time.

The route of the excursion from Montrose enters the San Juan Mountains by way of the north-south course of the Uncompahgre River, which has eroded a canyon within the range to a depth of 2,000 to 4,000 feet (610 to 1,220 meters) below the average altitude of the surrounding summits. The extreme relief within the range is nearly 6,000 feet (1,829 meters), and the average altitude in the Silverton quadrangle, in the central part of the mountains, is about 11,500 feet (3,505 meters). The physiographic features are those of a deeply dissected plateau, in which the forms of some of the peaks and ridges and the longer canyons have been modified by glacial erosion. The part of the range between Ouray and the Needle Mountains is composed chiefly of volcanic rocks, but the basement rocks of Mesozoic, Paleozoic, and pre-Cambrian age are exposed in some of the deeper canyons.

The Needle Mountains, the western part of which is crossed by the route between Silverton and Durango, lie between the volcanic mountains and the foothills of upturned sedimentary rocks on the south that fringe the northern edge of the San Juan Basin. Massive bodies of pre-Cambrian granite and of schist are the chief rocks in the central and western parts of the mountains, which are bounded on the north and east by a crescentic body of Algonkian quartzites, shales, and slates comprising the Grenadier Range. The peaks of the Needle Mountains, of which four rise over 14,000 feet (4,267 meters) above sea level, form a group of accordant summits that are about as high as the volcanic mountains of the San Juan, and they thus represent an uplifted portion of the basement rocks of the San Juan Moun-

tains. The average diameter of the Needle Mountain uplift is about 20 miles (32 kilometers). Canyons in the range from 2,000 to 4,000 feet (610 to 1,220 meters) in depth have been eroded by the Animas River and its tributaries. To the south the mountains are bounded by a granite plateau of slight southerly inclination, upon which there are remnants of early Paleozoic sedimentary rocks lying essentially undisturbed on the old Paleozoic land surface.

STRATIGRAPHY

In the inserted table the formations of the San Juan Mountains are listed and briefly described. It should be noted that the Silurian and Ordovician sedimentary rocks are not represented in the western part of the mountains. Great thicknesses of Upper Cretaceous sedimentary and volcanic formations, which presumably extended across at least the western part of this range, were destroyed by the erosion that preceded the deposition of the Telluride conglomerate. The hiatus thus produced can be partly inferred from the descriptions of the geologic formations of the San Juan Basin on pages 58–59.

GEOLOGIC HISTORY

The principal events of the geologic history of the western San Juan Mountains may be summarized as follows:

The pre-Cambrian history included the metamorphism of the Archean rocks into schists and greenstones by compression, accompanied possibly by granitic intrusions; great erosion and ensuing deposition of the Algonkian sedimentary rocks; the folding, faulting, and metamorphism of the Algonkian, accompanied and followed by granitic intrusions; and finally the erosion preceding Cambrian sedimentation.

The Paleozoic history is chiefly a record of sedimentation accompanied by only relatively minor changes in altitude. The chief hiatus in the Paleozoic record of this area is that of the Silurian sediments. Ordovician rocks also are unknown. The principal periods of erosion preceded the Devonian and Pennsylvanian sedimentation. The abundance of coarse conglomerates and cross-bedded sandstones in the upper part of the Paleozoic section and the discontinuity of beds in the Permian indicate that the sediments are of fluviatile origin or were deposited in shallow turbulent waters.

At the end of Paleozoic time and also partly in the Triassic, deformation occurred, arching the formations and locally developing monoclinal flexures and blocklike uplifts. Some of these features are well exposed in the Uncompahgre Canyon at Ouray. They are probably related in origin to the uplift of the early Mesozoic Uncompahgre highland, on the southwest flank

Geologic formations of the western San Juan Mountains

System	Series	Formation	Character	Thickness	
				Feet	Meters
Quaternary.	Recent.		River gravels, etc., landslide deposits.		
	Pleistocene.	Wisconsin till and outwash. Durango till and outwash. Cerro till and outwash.	Morainal deposits, outwash gravel and sand.		
	–Unconformity–				
Tertiary.	Miocene.	Potosi volcanic series.	An alternation of rhyolite and quartz latite flows and tuffs, flows predominating near the base.	2,000+	610+
	–Unconformity–				
	Miocene or Oligocene.	Silverton volcanic series.	A succession of pyroxene andesite, latite, and rhyolite flows, tuffs, and breccias. Includes some dikes and other intrusive rocks.	3,000+	914
		–Unconformity–			
		San Juan tuff.	Chiefly andesitic débris. Near the base is a well-stratified tuff, but the material becomes coarser and less distinctly stratified in upper part.	100–3,000	30–914
	–Unconformity–				
	Eocene.	Telluride conglomerate.	Chiefly a coarse conglomerate, containing pebbles and boulders of granite, schist, quartzite, porphyry, and the harder sediments of the Paleozoic and Mesozoic formations. In western part of San Juan Mountains (Mount Wilson) are sandstones, shales, and thin fresh-water limestones.	0–1,000	0–305
		–Unconformity–			
		Ridgway till.	Deposits of boulder till and pebble till composed of material from formations ranging from pre-Cambrian to Upper Cretaceous, and also some porphyries and volcanic rocks derived from the late Cretaceous volcanic formations (destroyed by erosion in San Juan Mountains).	0–200	0–61
	–Unconformity–				
Cretaceous.	Upper Cretaceous.	Mesaverde formation.	Gray or yellowish quartzose sandstones and sandy shales, with coal seams in upper part. Invertebrate fossils.	300+	91+
		Mancos shale.	Dark-gray or carbonaceous clay shale with thin lenses of limestone. Equivalent to Colorado group and part of Pierre shale of the Montana group. Marine invertebrate fossils.	1,200±	366±
		Dakota (?) sandstone.	Gray or rusty-brown quartzose sandstone with a conglomerate containing small chert pebbles at or near the base. Carbonaceous shale and coal of poor quality locally present.	100–300	30–91
	–Unconformity				
Cretaceous (?).	Lower Cretaceous (?).	Morrison formation.	Lower part white or gray sandstones, thin limestones, and brown or green shales. Upper part a complex of alternating yellowish or gray sandstones and variegated shales, chiefly green but also red or brown.	650–750	198–229
Jurassic.	Upper Jurassic.	Entrada sandstone.	Very massive friable white sandstone, distinctly cross-bedded, cliff-forming. Generally even grained and fine textured.	45–250	14–76
	–Unconformity–				
Triassic.	Upper Triassic.	Dolores formation.	Fine-grained bright-red sandstones, sandy marls, and shales. Limestone conglomerates and grits near base containing teeth of Triassic reptiles, carbonized and silicified wood, and leaves.	40–600	12–183
	–Unconformity–				
Carboniferous.	Permian.	Cutler formation.	A series of bright-red sandstones and pinkish grits and conglomerates alternating with reddish sandy shales and earthy limestones. Commonly unfossiliferous.	1,000–2,000	305–610
		Rico formation.	Dark reddish-brown sandstone and pinkish grit with intercalated greenish or reddish shale and sandy fossiliferous limestone.	0–300	0–91
	Pennsylvanian.	Hermosa formation.	A series of grits, sandstones, shales, and limestones of variable distribution and development. Some gypsiferous beds locally. Colors generally gray or green. Numerous marine invertebrate fossils in shales and limestones.	1,400–2,000	427–160
		Molas formation.	Red calcareous shale and sandstone with pebbles of quartzite, chert, and limestone containing Mississippian fossils. Thin limestone lenses carry Pennsylvanian fossils.	0–75	0–23
	–Unconformity–				
	Mississippian.	Leadville limestone.	Lower part predominantly dark blue-gray or brownish-gray limestone with sandy layers. Upper part more massive gray crystalline limestone, in places grading upward into alternations of limestone and red shales or breccia beds. Fossiliferous.	70–230	21–70
Devonian.	Upper Devonian.	Ouray limestone.	Predominantly gray, buff, white, or pinkish limestones, generally well bedded; lower part shaly with thin quartzites in places. Locally contains Upper Devonian invertebrates.	70–120	21–37
		Elbert formation.	Thin-bedded limestone, sandstone, and calcareous shales. Contains fish remains of Devonian types.	0–80	0–24
	–Unconformity–				
Cambrian.	Upper Cambrian.	Ignacio quartzite.	Quartzite, massive and conglomeratic in lower part, thin bedded with shaly or sandy partings in medial zone, succeeded by more massive quartzite. *Obolus* sp.? only fossil found.	0–200	0–61
	–Unconformity–				
Algonkian.		Uncompahgre formation.	Massive and some thin-bedded quartzite and bands of shale or slate; quartzites white, pink, and brown to black; shales rusty brown or black.	5,000–8,000	1,524–2,438
		Vallecito conglomerate.	Coarse conglomerate consisting of pebbles and boulders of quartzite and greenstone, with some jasper.	1,000±	305±
	–Unconformity–				
Algonkian (?).		Irving greenstone.	Greenstone, greenstone porphyry, and greenstone schist, with subordinate quartz-mica schist and granite gneiss.	10,000	3,048
Archean.		Schist, gneiss, and granite.[a]	Quartz-mica and amphibole schists and some granite gneiss, much crumpled and contorted.		

[a] Some of the granite of the area is intrusive into the Algonkian rocks.

of which this part of the San Juan Mountains is situated. These periods of deformation were attended and followed by erosion, which culminated in a peneplained surface upon which the Upper Triassic and Jurassic formations were deposited.

The Mesozoic era was characterized by continental sedimentation in the Upper Triassic, Jurassic, and Cretaceous (?) (Morrison time) and by the accumulation of thick marine sediments in the Upper Cretaceous. In the later part of Upper Cretacous time there were alternations of fluviatile and marine conditions, and the Cretaceous period ended with crustal disturbances and extensive volcanic eruptions in the San Juan region.

The volcanic eruptions of the late Cretaceous probably continued into earliest Tertiary time and were accompanied or followed by intrusions of monzonitic rocks. A domal uplift of the western San Juan Mountains took place, and probably during this period the quaquaversal uplift of the Needle Mountain pre-Cambrian rocks occurred or was accentuated to produce its present condition. A line of laccolithic mountains was developed on the western flank of the main San Juan dome, probably in Eocene time, by intrusion of the monzonitic magmas, one intrusive center of which is represented by the stock and laccoliths at Ouray and others probably by the intrusions of the Rico and La Plata Mountains. Mineralization accompanied the intrusions, forming productive fissure veins and also replacement deposits in the sedimentary beds near these intrusive centers.

The early Tertiary was a period of continued uplift and erosion in the San Juan Mountains, and the high altitudes of the mountain ranges gave rise for a time to glaciation resulting in the Ridgway till, but continued erosion finally reduced this first generation of the San Juan Mountains to a land of low relief. Within the range most of the Cretaceous rocks were destroyed by this erosion, and the material of the volcanic eruptions was transported and deposited in near-by basins of sedimentation. (See pp. 58–59.)

In later Eocene time the Telluride conglomerate was deposited by streams on the peneplained surface, but further erosion followed, before the great Tertiary volcanic eruptions began. These eruptions probably reached their maximum intensity in Miocene time but may have continued into the Pliocene. Four principal series of eruptive deposits are differentiated—the San Juan tuff, the Silverton volcanic series, the Potosi volcanic series, and the Hinsdale volcanic series. These major series were separated by intervals of erosion during which canyons and broader valleys were formed, but even during the eruptions erosion was active locally.

After the eruption of the Potosi volcanic series in the western San Juan Mountains large bodies of intrusive rocks penetrated the volcanic formations, widespread fissuring and some tilting of the formations occurred, and as a consequence of these disturbances there was another period of mineralization in the San Juan region. Fissure veins were formed in the volcanic rocks of the Silverton, Telluride, Ouray, and Red Mountain districts, as well as in more distant parts of the region. To some extent this metallogenetic activity formed mineral deposits in the sedimentary and pre-Cambrian metamorphic rocks of the basement, but their production has been much less than that of the deposits found at higher horizons in the lavas.

With the cessation of volcanism dissection of the volcanic plateau began, and after a considerable period of erosion, which produced the present summit peneplain, warping or doming of the area again occurred and valleys were cut by the rejuvenated streams. These valleys were later occupied and widened by the early Pleistocene glaciers. Uplift of the range continued throughout Pleistocene time. Several stages of glaciation and valley cutting have produced the characteristic effects in the mountains and neighboring plains that have been briefly described above (1, 4, 5).

ROAD LOG—CONTINUED

From Montrose (altitude 5,800 feet, or 1,768 meters) the highway goes southeastward on the Wisconsin outwash plain, which is only 20 to 30 feet (6 to 9 meters) above the modern flood plain of the Uncompahgre River. Due west of Montrose may be seen the flat surface of Spring Creek Mesa, a terrace about 50 feet (15 meters) above the Wisconsin outwash, formed by the Uncompahgre River during the post-Durango and pre-Wisconsin interglacial stage. The west side of the valley is formed by the eastern slope of the Uncompahgre Plateau, which is underlain mainly by the Dakota (?) sandstone, but in a narrow strip along the river valley the Mancos shale is not entirely eroded. The east side of the valley is bordered by low hills and gravel-covered mesas composed of Mancos shale.

A few miles beyond Colona (12.9 miles, or 20.8 kilometers [6]) the road enters a narrow gorge of the river where the Dakota (?) sandstone (14.5 miles, or 23.3 kilometers) and Morrison formation (15.4 miles, or 24.8 kilometers) are exposed by a domal fold superimposed on the northeasterly dip slope of the Uncompahgre Plateau.

Just beyond the junction of Dallas Creek with the Uncompahgre River the valley broadens again (25 miles, or 40 kilo-

[6] Distances from Montrose.

meters), owing to an east-west fault that brings the base of the Mancos shale below the valley bottom. From this place an excellent view is obtained of the structure of the San Juan Mountain front. The summit of Sneffels Peak (altitude 14,158 feet, or 4,315 meters), a dioritic intrusive mass, rises above the general level of the bedded volcanic formations in the mountain front to the south. The terminal moraine of the last advance of the Wisconsin valley glacier is also seen at this point, forming a ridge over 400 feet (122 meters) in height, which has been cut through about in the middle by the Uncompahgre River. Below the moraine the outwash gravel is about 60 feet (18 meters) above the river. The morainal deposits of the Durango glacier cap the Dakota (?) sandstone and Mancos shale on each side of the valley about 1 to 2 miles (1.6 to 3.2 kilometers) farther north and about 500 feet (152 meters) above the river. About 2 miles (3.2 kilometers) to the southwest is a prominent bluff west of the town of Ridgway, which is the type locality of the Ridgway till, of Eocene age. The Ridgway till appears from this distance as a distinct yellow band, up about three-quarters of the height of the bluffs, and is over 100 feet (30 meters) in thickness.

The sharp upturning of the beds as the San Juan Mountains are approached is the result of the domal uplift of the mountain area in late Cretaceous or early Tertiary time. About 28.8 miles (46.3 kilometers) from Montrose the Morrison and Dakota (?) reappear from beneath the valley and may be seen dipping northward on the ridges at both sides. At about 30.5 miles (49.1 kilometers) the Dakota (?) and Morrison at the left (east) of the road rise abruptly and expose the white Jurassic sandstone (Entrada) and underlying red Upper Triassic beds (Dolores). At this point the beds are cut by a north-south dike of diabase.

The Triassic formation is less than 100 feet (30 meters) in thickness here, and for the remainder of the distance nearly to Ouray the lower walls of the Uncompahgre Valley are composed of the Permian (Cutler) red beds.

At 36 miles (58 kilometers) a sharp monoclinal fold in the Cutler is seen on the right (west) side of the valley. This fold, though resembling the one seen farther down the valley, is much older and does not affect formations younger than the Cutler. The Triassic beds dip gently northward and bevel the upturned Cutler beds.

Just before the route enters the town of Ouray the Pennsylvanian (Hermosa) beds appear in the valley bottom (36.5 miles, or 58.7 kilometers) and are much fissured and intruded by dikes and sills of quartz monzonite porphyry, which are offshoots of

the late Cretaceous or Eocene stock that lies just northeast of the town. Ouray (altitude 7,803 feet, or 2,378.3 meters) is reached at 37.5 miles (60.4 kilometers).

[Road log continued on p. 46.]

OURAY MINING DISTRICT

The town of Ouray was established in 1875 and since that time has been an important mining center for the western San Juan Mountains. It is named in honor of a Ute chief, who was well known for his friendliness to the early white settlers. Although most of the mineral production of this section of the San Juan Mountains came from the mining districts in the volcanic rocks of the neighboring mountains, several mines on the precipitous slopes of the Uncompahgre Canyon just north of the town have made a notable output from the sedimentary formations. The Ouray mining district proper includes mainly these mines in the sedimentary rocks within a radius of several miles from Ouray, but the development of several large mines, such as the Camp Bird and Virginius, in the volcanic formations southwest of Ouray is closely associated with the history of the town.

Ore deposits of two ages have been recognized in the San Juan Mountains. The older deposits, of Eocene age, are found chiefly in the Paleozoic and Mesozoic formations on the western edge of the San Juan uplift; the younger deposits, of late Miocene or post-Miocene age, are widely distributed in the volcanic formations that rest upon the eroded pre-Tertiary basement. As might be expected, veins of the later period also extend into the basement rocks, but these deeper parts of the veins have not yet proved to be productive. As deposits of both ages are present essentially within sight of the town of Ouray, this region includes nearly all the geologic and metallogenetic features of the western San Juan Mountains.

The production of the district has been rather large, especially from near-by mines in the volcanic rocks. It is essential from the viewpoint of the geologist to distinguish the production derived from deposits of the earlier mineralization from that derived from deposits of the later period, but the total production from the sedimentary formations near Ouray is only roughly known—it is probably between $5,000,000 and $10,000,000. Because of the wide distribution of the veins in the lavas and the great length of some of the mineralized areas, the production of the late Tertiary ore deposits can not be given in any detail. However, the combined production of a few of

the principal mines in these deposits, such as the Camp Bird ($27,269,768 to 1916, chiefly gold), Virginius ($4,000,000), Klondike, Atlas, Terrible, and others lying southwest of Ouray and tributary to Canyon Creek, has far exceeded the production from early Tertiary ore deposits. Veins in the volcanic rocks that belong to the same mineralized area but lie across the divide in the drainage basin of the San Miguel River at Telluride have been equally productive; these include the Smuggler Union ($26,000,000), Tomboy ($22,235,883), and Liberty Bell ($16,171,089). Further details of the production of these and other San Juan districts are given by Henderson (17).

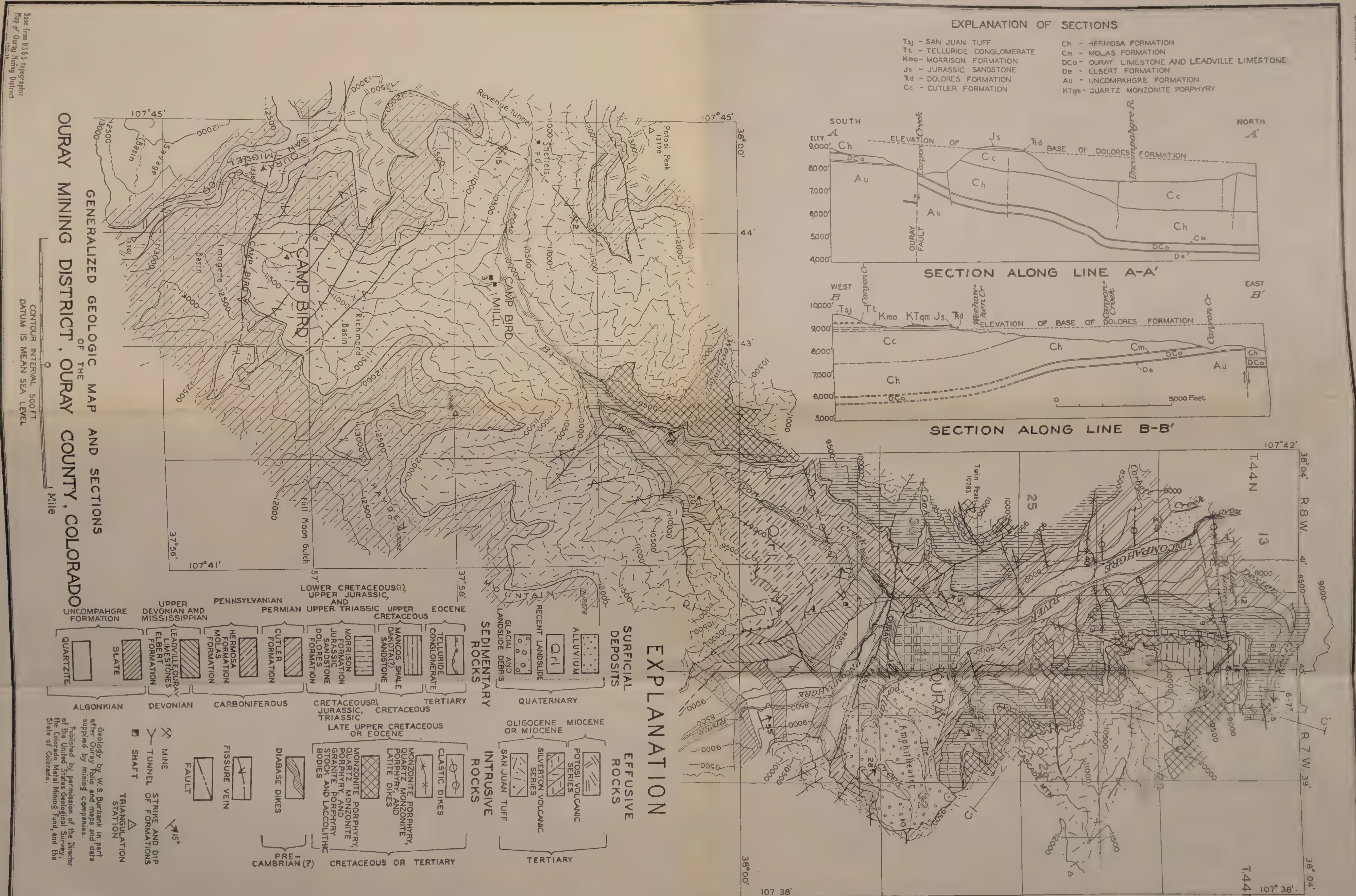
Geology.—The geologic formations of the Ouray district include most of those described in the table at page 36.

A generalized geologic map and a cross section of the structure of the district are shown in Plate 5 and Figure 8. One of the main features of the geologic structure is the pronounced domal uplift of earlier than Upper Triassic age which brought up the Uncompahgre quartzites and the lower Paleozoic formations so that they are now exposed in the canyon. The angular unconformity at the base of the Dolores formation (Upper Triassic) may be readily seen in the cliffs northeast of Ouray. In the cliffs south of Ouray the Elbert formation (Devonian) rests upon the quartzites of the Uncompahgre formation (Algonkian) and is about 4,000 feet (1,219 meters) higher than its normal position several miles north of Ouray.

Other noteworthy elements of the structure are the moderate regional northwesterly tilting of the formations, including the Mesozoic, and the local tilting and doming near the Ouray stock. These deformations are the result of the late Cretaceous and early Tertiary uplift of the San Juan dome, with which the intrusions of the Ouray stock, laccoliths, sills, and dikes were associated. It was during this period of deformation that the earlier ore deposits in the sedimentary formations near Ouray were formed.

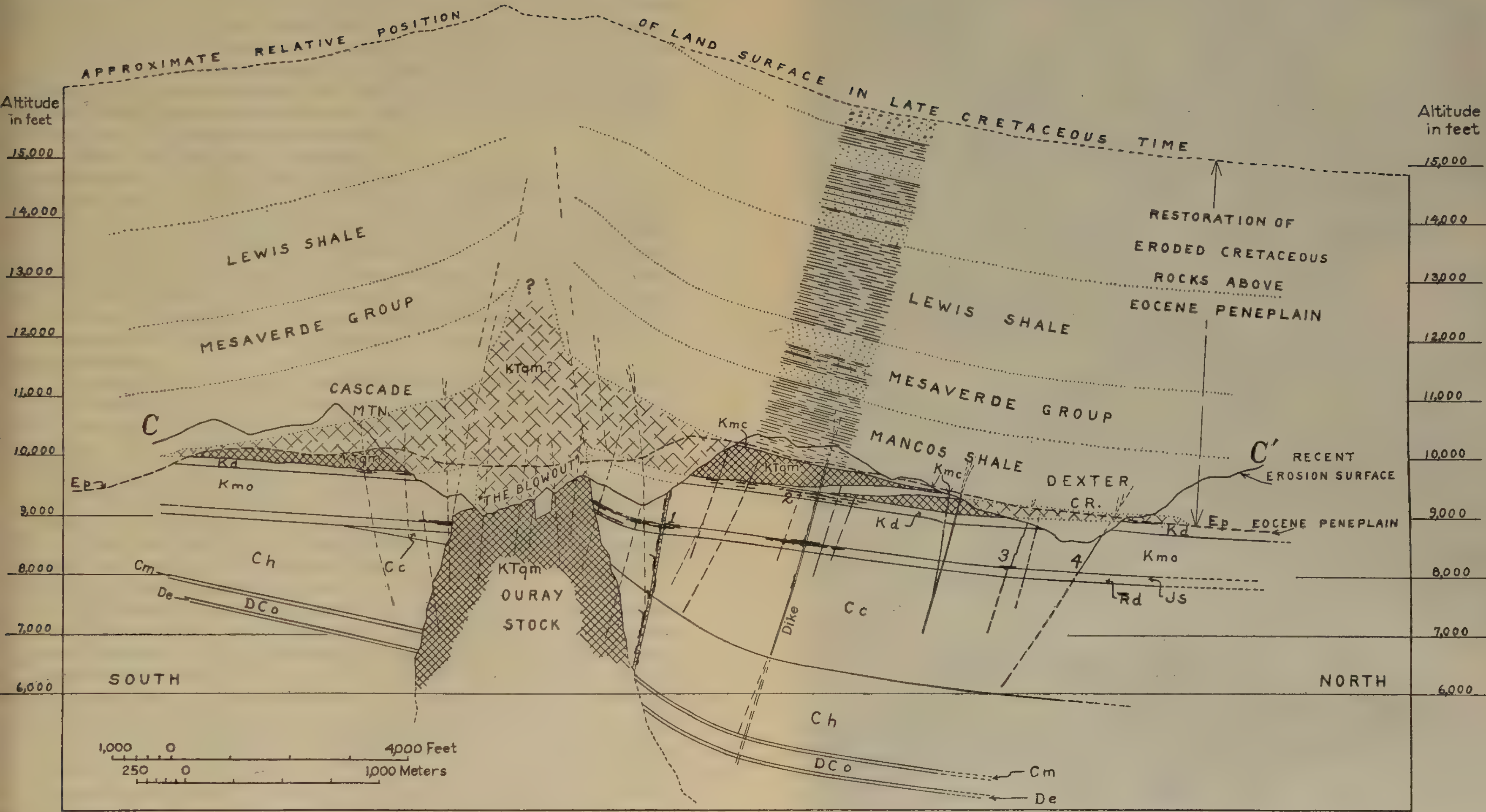
The Telluride conglomerate is nearly horizontal in the immediate vicinity of Ouray. The surface upon which it rests, however, is irregular, and several monadnocks rise above its general level. These early Tertiary hills were produced by laccolithic bodies of quartz monzonite porphyry and by the resistant quartzites of the Uncompahgre formation. Hills of monzonite reached a height of about 1,200 feet (366 meters) above the Tertiary plain, but the quartzite hills were lower, as this formation had also been subjected to erosion in the pre-Upper Triassic peneplanation, and its surface had been reduced to a level below that at which the laccoliths were intruded. Several of the earlier ore deposits at Ouray cropped out on this early

FIGURE 8.—Geologic section across the Uncompahgre Canyon at Ouray, along line *D–D′*, Plate 5. Qlt, Landslide and till; Tsj, San Juan tuff (Oligocene or Miocene); Tt, Telluride conglomerate (Eocene); KTi, early Eocene quartz monzonite porphyry; Kd, Dakota (?) sandstone (Upper Cretaceous); Km, Morrison formation (Lower Cretaceous ?); ŦJ, Upper Jurassic sandstone and Dolores formation; Cc, Cutler formation (Permian); Chm, Hermosa and Molas formations (Pennsylvanian); Cl, Leadville limestone (Mississippian); Do, Ouray limestone (Upper Devonian); De, Elbert formation (Upper Devonian); db, diabase dike; Au, Uncompahgre formation (Algonkian), with slate bands (Aus)



GENERALIZED GEOLOGIC MAP AND SECTIONS OF THE OURAY MINING DISTRICT, OURAY COUNTY, COLORADO
CONTOUR INTERVAL 500 FT.
DATUM IS MEAN SEA LEVEL
1 Mile
Base from U.S.G.S. topographic Map of Ouray Mining District
EXPLANATION OF SECTIONS
Tsj - SAN JUAN TUFF
Tt - TELLURIDE CONGLOMERATE
Kmo - MORRISON FORMATION
Js - JURASSIC SANDSTONE
Ꞧd - DOLORES FORMATION
Cc - CUTLER FORMATION
Ch - HERMOSA FORMATION
Cm - MOLAS FORMATION
DCo - OURAY LIMESTONE AND LEADVILLE LIMESTONE
De - ELBERT FORMATION
Au - UNCOMPAHGRE FORMATION
KTqm - QUARTZ MONZONITE PORPHYRY
SOUTH A
NORTH A'
ELEVATION OF BASE OF DOLORES FORMATION
OURAY FAULT
SECTION ALONG LINE A-A'
WEST B
EAST B'
5000 Feet
SECTION ALONG LINE B-B'
CAMP BIRD
CAMP BIRD MILL
Revenue tunnel
Potosi Peak 13790
Imogene Basin
Richmond Basin
Full Moon Gulch
Twin Peaks 10783
UNCOMPAHGRE RIVER
OURAY
The Amphitheatre
CASCADE MTN
T.44 N.
R.8 W.
R.7 W.
107°45'
107°42'
107°41'
107°38'
38°00'
38°04'
37°56'
37°58'
EXPLANATION
SURFICIAL DEPOSITS
ALLUVIUM
RECENT LANDSLIDE
GLACIAL AND LANDSLIDE DEBRIS
QUATERNARY
SEDIMENTARY ROCKS
TELLURIDE CONGLOMERATE
EOCENE
TERTIARY
MANCOS SHALE DAKOTA(?) SANDSTONE
UPPER CRETACEOUS
CRETACEOUS
MORRISON FORMATION JURASSIC SANDSTONE DOLORES FORMATION
LOWER CRETACEOUS(?), UPPER JURASSIC, AND UPPER TRIASSIC
CRETACEOUS(?), JURASSIC, TRIASSIC
CUTLER FORMATION
PERMIAN
HERMOSA FORMATION MOLAS FORMATION
PENNSYLVANIAN
CARBONIFEROUS
LEADVILLE-OURAY LIMESTONES ELBERT FORMATION
UPPER DEVONIAN AND MISSISSIPPIAN
DEVONIAN
SLATE
QUARTZITE
UNCOMPAHGRE FORMATION
ALGONKIAN
EFFUSIVE ROCKS
POTOSI VOLCANIC SERIES
MIOCENE
SILVERTON VOLCANIC SERIES
OLIGOCENE OR MIOCENE
SAN JUAN TUFF
TERTIARY
INTRUSIVE ROCKS
CLASTIC DIKES
MONZONITE PORPHYRY, QUARTZ MONZONITE PORPHYRY, AND LATITE DIKES
MONZONITE PORPHYRY, QUARTZ MONZONITE PORPHYRY, AND GRANITE PORPHYRY STOCK AND LACCOLITHIC BODIES
LATE UPPER CRETACEOUS OR EOCENE
CRETACEOUS OR TERTIARY
DIABASE DIKES
PRE-CAMBRIAN (?)
FISSURE VEIN
FAULT
MINE
TUNNEL
SHAFT
STRIKE AND DIP OF FORMATIONS
TRIANGULATION STATION
Geology by W.S. Burbank in part after Ouray Folio and maps and data supplied by mining companies.
Published by permission of the Director of the United States Geological Survey, the Colorado Metal Mining Fund, and the State of Colorado.

PLATE 5



RESTORATION SHOWING PROBABLE GEOLOGIC ENVIRONMENT OF THE OURAY STOCK IN LATE UPPER CRETACEOUS OR EARLY EOCENE TIME

Kd, Dakota(?) sandstone; KTqm, quartz monzonite porphyry; Kmc, Mancos shale; Ep, Eocene peneplain. For line C–C′ and explanation of other symbols see Plate 5.

Tertiary land surface, and some were partly or totally destroyed by erosion, while others were subjected to shallow oxidation and possibly enrichment. The exact effect of this superficial alteration has not been determined, because few deposits are so located as to permit examination of their ancient outcrops. Some of them, however—for example, the Bachelor vein—were protected from deep alteration by thin coverings of the relatively impervious Mancos shale, and others—for example, the American Nettie replacement deposits—by thick laccolithic bodies of porphyry that had resisted erosion.

Minor faulting was associated with each of the periods of deformation, but the northwestward-trending Ouray fault is the largest, with a displacement of 400 to 1,000 (?) feet (122 to 305 meters). The major displacement on this fault is considered to have occurred before Upper Triassic time, although there has been later movement on it, as shown by fracturing of the younger formations above the line of the fault. This fault is well exposed at the box canyon of Canyon Creek, where the Hermosa formation is faulted down against the Devonian and pre-Cambrian rocks.

Ore deposits of the first metallogenetic epoch.—The conditions that favored laccolithic intrusions during late Cretaceous and Eocene time also favored the formation of replacement ore bodies in the sedimentary beds. The existence of blanket deposits and the tendency shown for the fissure fillings of this epoch to spread laterally, producing deposits that exhibit the structural features of both types, are distinctive physical characteristics of the earlier mineralization. In Plate 6 an attempt has been made to reconstruct the geologic setting under which these ore deposits were formed.

The Ouray stock of quartz monzonite porphyry penetrated the Mancos shale, and in the readjustment of the crust fissures were formed in the surrounding sedimentary rocks. These fissures permitted the escape of gases and vapors to the surface, in places with explosive force, as clastic dikes composed of fragments of underlying formations were injected into fissures in the rocks surrounding the stock. Many of the fissures penetrated the yielding shales of the Upper Cretaceous for short distances only, and the later ore-depositing solutions ascending in them were forced to spread laterally and seek other channels to regions of lower pressure. The sedimentary beds of greater permeability therefore served as channels for the lateral diversion of the ore-bearing solutions, and where conditions were favorable ore deposits of the blanket type were formed in these permeable beds. Where the fissures were wider and the ascend-

113723—32——4

ing solutions were less obstructed veins of the ordinary kind were formed. Essentially all gradations between these two types exist.

The ore deposits exhibit a zonal distribution with respect to the center of greatest hydrothermal activity near the Ouray stock. In the immediate vicinity of the stock itself the alteration was very intense, resulting in the feldspathization and silicification of the rocks and the formation of other hydrothermal minerals, such as sericite, epidote, chlorite, and carbonates.

Nearest to the north side of the Ouray stock are the contact-metamorphic (pyrometasomatic) deposits of the Bright Diamond or Wanakah and Iron Clad mines, on the east wall of the Uncompahgre Canyon about 1,200 feet (366 meters) above the river. These deposits have replaced slightly tilted limestone-breccia beds and sandstones in the basal part of the Morrison formation. They are overlain by green shales that have been altered to a dense argillite heavily charged with epidote and other metamorphic minerals, and the ore is in flat shoots that are sharply conformable to the stratification. The ore of the Wanakah mine ranges from low-grade magnetite ore containing magnetite, pyrite, chalcopyrite, garnet, actinolite, epidote, quartz, and calcite to massive ore consisting largely of pyrite. There are some shoots of galena ore. The massive pyritic ore contains gold-bearing lenses or shoots.

Several longitudinal fissures and cross fissures are associated with the ore body, and presumably gold was introduced into the massive sulphide ore along fractures by a late phase of the mineralization, as in the American Nettie mine.

Veins adjacent to or within the stock include barren pyrite veins and gold-bearing pyrite and chalcopyrite veins. The copper minerals are chiefly chalcopyrite and bornite, and the gangue is made up chiefly of quartz, altered country rock, and gouge clay. The ore occurs in small shoots in fissures or sheeted zones and is so irregular in distribution that economical mining is difficult. In general, replacement of the immediate wall rock was relatively common, presumably because of the high temperature of the country rock and the ore-forming solutions.

The gold-bearing replacement deposits of the American Nettie mine are several thousand feet north of the Ouray stock, in the Dakota(?) sandstone, which is locally altered to quartzite. The mine is on the cliffs east of and about 1,800 feet (549 meters) above the Uncompahgre River. The stratigraphic position of the ore bodies in the sedimentary beds is shown in Plate 6. The primary ores consist of pyrite, chalcopyrite, sphalerite, galena, tellurides of gold and silver, argentiferous tetrahedrite, and molybdenite. Pyrite is the most abundant sulphide, and

barite and quartz are common gangue minerals. The quartzite near the ore and adjacent to some of the more strongly mineralized fissures has been extensively replaced by sericite. The Dakota(?) quartzite in the mine is seamed by a great number of irregular fissures, several major fissures, monzonite porphyry dikes, and one prominent clastic dike. The mineralizing solutions appear to have moved up the slight dip of the quartzite, aided or guided by the fractures and the permeability of the beds. Extensive microscopic fracturing of the massive pyrite has facilitated its replacement in turn by later sulphides. Tellurides of gold and silver and native gold represent the latest phases of mineralization. In a few places cavities were formed in the quartzite and later filled with quartz and sulphide minerals, but probably not much of the ore is due to this process.

The Bachelor mine, which was developed on the most productive of the silver-bearing veins, is about 2½ miles (4 kilometers) north of Ouray, on the east side of the Uncompahgre Valley. In this mine are two steep fissure veins of east-west strike. Prior to the formation of the ore bodies parts of the fissures were filled by injection with clastic material derived from underlying formations and from portions of the more immediate wall rock. The injection of these "clastic dikes" was presumably caused by the violent escape of volcanic gases and vapors, such as occasionally attends modern volcanic eruptions. Reopening of fractures along the dikes and earlier fissures permitted the access of the later mineralizing solutions. The ore of the Bachelor mine consists chiefly of galena, sphalerite, chalcopyrite, tetrahedrite (freibergite?), pearcite, and ruby silver (pyrargyrite), in a gangue of quartz, barite, and manganiferous calcite. Gold is present only in very small quantities, and there is also a little pyrite. The character of the wall rock has greatly influenced the distribution of ore shoots, the harder rocks being the more favorable to the existence of open or permeable zones. Along a number of shale beds the fissures are offset laterally so that the upper and lower portions of the vein are separated by 30 feet (9 meters), more or less, of nearly horizontal vein matter. There appears to have been lateral migration of the ore solutions along the strike of the vein.

Ore deposits of late Tertiary age.—The late Tertiary ore deposits are mostly fissure veins containing silver and gold and the common base metals. The most productive mineralized region is tributary to Canyon Creek 5 to 6 miles (8 to 10 kilometers) southwest of Ouray and extends across the divide to the mines of the Telluride district. It covers an area of 12 to 15 square miles (31 to 39 square kilometers), and some of the veins exhibited remarkable continuity both longitudinally and

in depth. The Smuggler vein, near Telluride, has been mined continuously for 8,000 feet (2,438 meters) and through a vertical distance of 2,300 feet (701 meters). Another area of late Tertiary mineralization is in the high mountains, 6 to 7 miles (9 to 11 kilometers) southeast of Ouray, adjacent to Poughkeepsie Gulch and Mineral Point.

ROAD LOG—CONTINUED

On leaving Ouray the road mounts by a series of switchbacks on the dip slope of the Mississippian limestone (Leadville limestone) to the edge of a bench above the recent gorge of the Uncompahgre River.

At about 1.8 miles (2.9 kilometers) from Ouray, at the top of the switchbacks, the road goes through a narrow cut in the limestone, which is in fault contact with the slate of the Uncompahgre formation (Algonkian). (See fig. 8.) From this point a good view is obtained to the west, across the valley, of the nearly vertical beds of the Algonkian quartzite and slate, upon which Devonian beds (Elbert formation and Ouray limestone) rest unconformably. The high cliffs of Hayden Mountain above consist of the San Juan tuff, which at the north end of the mountain rests upon the basal part of the Pennsylvanian beds (Hermosa). A mile or so farther south on this west side of the valley the Paleozoic beds are eroded, and the tuff rests directly on the Algonkian.

From this point onward the road is cut in the precipitous east wall of the Uncompahgre Canyon, and alternate bands of the quartzite and slate may be seen in the cuts.

A little over 3 miles (4.8 kilometers) south of Ouray is the Bear Creek Falls, 253 feet (77 meters) in height, which plunges into the recent gorge of the Uncompahgre River from a narrow hanging channel cut along the contact of a slate band with a quartzite band of the Uncompahgre formation.

The lower part of the canyon of the river above Bear Creek Falls continues in the Algonkian rocks for several miles, with the San Juan tuff forming the mountain slopes above. At 43.2 miles (69.7 kilometers) from Montrose the San Juan tuff is exposed at the road level, and less than a mile beyond this point the road enters Ironton Park.

The mountain slopes above Ironton Park are composed of the San Juan tuff and lava flows of the overlying Silverton volcanic series. The broad, flat expanse of the valley is partly underlain by the sandstones and shales of the Hermosa formation, which are exposed low down on the west side of the valley. An east-west section showing the geologic structure of Ironton Park is given in Figure 9.

Where the road crosses the small bridge in the center of the park (45.5 miles, or 73.2 kilometers; altitude 9,644 feet, or 2,939 meters), a view is obtained of the old Saratoga mine and lixiviation plant at the east edge of the valley (left of road). The ore body of the Saratoga mine is due to a replacement of the Devonian and Mississippian (?) limestone and rests a little above the level of the park on quartzite presumably belonging to the Algonkian. The ore is largely pyrite, with some bodies carrying galena, chalcopyrite, and oxidized material, together with silver and gold.

The road turns southwestward out of Ironton Park through the town of Ironton (46.5 miles, or 74.8 kilometers) and crosses to the west slope of the valley and thence to the Red Mountain mining camp (49.5 miles, or 79.7 kilometers; altitude 10,600 feet, or 3,230 meters). The most striking scenic as well as geologic features of the Red Mountain district are the several

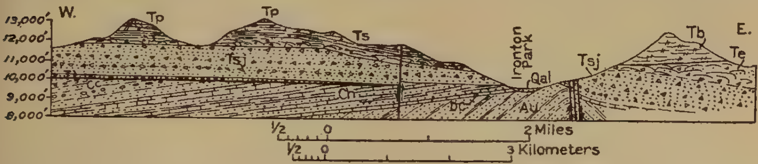


FIGURE 9.—Geologic section across Ironton Park. After Cross, Howe, and Spencer (13), with additions. Au, Uncompahgre formation; DC, Devonian (Ouray) and Mississippian (Leadville) limestones; Ch, Hermosa formation; Cc, Cutler formation; Tt, Telluride conglomerate; Tsj, San Juan tuff; Ts, undivided Silverton volcanic series; Te, Eureka rhyolite of Silverton volcanic series; Tb, Burns latite of Silverton volcanic series; Tp, Potosi volcanic series; Qal, alluvium

high peaks east of the valley, which are brilliantly colored by iron oxide formed by the oxidation of pyrite in the intensely altered rocks of the region. The crest of one of the prominent peaks is formed by an intrusive body of late Tertiary syenite porphyry; the other peaks and the lower slopes are composed of altered volcanic rocks of the Silverton series. The rocks forming the floor of the valley are chiefly andesitic breccias, with some tuffs and flows of massive andesite. A brief description of the mines of the district is inserted below. The road log is continued on page 49.

RED MOUNTAIN DISTRICT

The ore deposits of the Red Mountain district were discovered in 1881, and mining activity steadily increased until 1893, when the fall in the price of silver and the exhaustion of the rich silver shoots of the ore bodies started a very rapid decline of activity.

The Yankee Girl and Guston mines, which together produced at least $6,000,000, continued production until 1896. There has been but little production from the mines of the district since this early period of activity.

The ore bodies in their broader features are chimneylike stocks, consisting of nearly vertical mineralized zones of roughly elliptical outlines. The ore mined was bounded on some sides by fracture or fault planes within the mineralized zone and was concentrated in subsidiary chimneys, fractured rock, and vein-like bodies. Most of the solid chimney ore bodies are surrounded by envelopes of silicified country rock, and others lie adjacent to silicified bodies of rock. About these silicified zones the volcanic rocks are kaolinized, sericitized, and pyritized, and between several of the neighboring ore chimneys of the district there is a zone of much decomposed fissured rock. Most of the more productive ore bodies are grouped about a line of fracturing in a belt less than 1 mile (1.6 kilometers) wide and about 4 miles (6.4 kilometers) long, bearing about N. 21° E.

The more common minerals of the ores are galena, sphalerite, tetrahedrite, enargite, chalcocite, stromeyerite, bornite, chalcopyrite, and pyrite. The highest silver content was found in association with the copper minerals, but these ores contained also a number of other silver-bearing minerals, including cosalite, kobellite, proustite, and polybasite. Besides quartz, kaolin, and silicified country rock, barite is commonly present as a gangue mineral. The average price paid for Guston ore at the smelter was $91.81 a ton ($82.63 a metric ton) for a period of eight years. The richest ore was taken from the Guston in 1891 and carried 15,000 ounces of silver and 3 ounces of gold to the ton (419,958 grams of silver and 93 grams of gold to the metric ton). The ores found near the surface, consisting chiefly of argentiferous galena, changed at a depth usually less than 300 feet (91 meters) to highly argentiferous silver-copper ores, which in turn decreased in value downward through the increasing proportion of low-grade pyrite. The deepest workings of the district are from 1,000 to 1,300 feet (305 to 396 meters) below the surface.

The origin of the spaces that were filled with ore is believed by Ransome (21) to be due to enlargement of complex intersecting fissure sets by solution and metasomatic replacement. The silicification and widespread decomposition of the rocks in the vicinity of the mines of this district were accompanied by the formation of kaolin and diaspore—an alteration probably attributable to fumarolic and hot-spring action in the volcanic rocks of the San Juan Mountains. After the fumarolic emanations had altered and partly dissolved the rock constituents in the vicinity of the fissures, the resulting porous or cavernous

zones presumably formed the ore channels through which later mineralizing solutions ascended. Since the formation of the ore, certainly not less than 3,000 feet (914 meters) of lava has been removed by erosion from above the present outcrops of the ore shoots.

ROAD LOG—CONTINUED

From the Red Mountain district the road continues to climb to the summit of Red Mountain Pass (51.5 miles or 82.8 kilometers) which is at an altitude of 11,025 feet (3,361 meters), and then descends along the west side of Mineral Creek Valley.

A little less than a mile beyond the pass the road goes along the edge of a down-faulted block of altered rhyolitic lava, probably belonging to the Potosi volcanic series. Beyond this the road turns westward into the valley at the junction of Mill Creek and Mineral Creek and descends to the level of the alluvium.

The road continues almost due south along Mineral Creek. A good view of the glacial cirques on Sultan Mountain (altitude 13,336 feet, or 4,065 meters) and Bear Mountain (12,950 feet or 3,947 meters) is obtained ahead from parts of this road. The north slopes of these mountains are composed of a large stock of late Tertiary quartz monzonite, which intrudes the Hermosa and Cutler formations and the overlying San Juan tuff. The volcanic rocks on the west side of the valley comprise the San Juan tuff on the lower slopes and the Silverton lavas 1,500 to 2,500 feet (457 to 762 meters) above the valley bottom.

At the junction of the South Fork of the Animas River (58.7 miles or 94.5 kilometers) a view up its valley to the west (right) shows the red beds of the Cutler formation (Permian) underlying the San Juan tuff.

The road continues down the valley of the South Fork in a southeasterly direction, with the intrusive rock of Bear and Sultan Mountains on the right and the altered lavas of the Silverton volcanic series on the mountain slope to the left (northeast).

At 61.5 miles (99 kilometers) the road turns northwest into the town of Silverton (altitude 9,270 feet, or 2,825 meters), just above the junction of the Animas River and the South Fork.

SILVERTON MINING DISTRICT

In the year 1860 a large party of miners penetrated the San Juan Mountains to the present site of the town of Silverton, prior to which but few white men had visited this area. Many of this party perished when overtaken by the heavy winter snows, and it was not until several years later that active prospecting was resumed. In 1870 the first mine was successfully operated

on some gold ore from the Little Giant vein, in Arrastre Gulch, and about 1890 the first important attempt was made to concentrate low-grade ores. Production from this district and other mines of San Juan County increased until 1895 and has since fluctuated between $1,000,000 and $3,000,000 annually, although some years have shown a sharp falling off in production.

FIGURE 10.—Geologic map of part of Silverton district showing principal veins. ls, Landslide; Q, alluvium, torrential fans, rock streams, and moraines; Chm, Molas and Hermosa formations (Pennsylvanian); DC, Elbert formation and Ouray limestone (Upper Devonian) and Leadville limestone (Mississippian); Ꞓi, Ignacio quartzite (Upper Cambrian); ARs, Archean (?) schist and gneiss; Ti, quartz monzonite, stock and dikes, and intrusive porphyries, dikes, small stocks, and laccoliths (all late Tertiary); T, Telluride conglomerate (Eocene ?), Oligocene or Miocene volcanic rocks, San Juan tuff, and Silverton volcanic series undivided

In 1917 one of the first serious attempts to apply the process of selective flotation in America was started and carried through to success by the United States Smelting, Refining & Mining Co. on the complex Sunnyside ore. Of recent years the most active mining operations have been those at the Sunnyside mine, near Eureka Gulch, about 7 miles (11 kilometers) directly northeast of Silverton, and those of the Shenandoah-Dives Mining Co.

on the Mayflower-North Star vein, in Arrastre Gulch several miles east of the town.

Geology.—The general distribution and structure of the geologic formations in the vicinity of Silverton are shown in Figure 10, but the map includes only part of the mineralized area of the Silverton quadrangle. The Animas River south of Silverton has excavated a canyon below the level of the volcanic formations, revealing the underlying pre-Cambrian schist and Paleozoic formations.

In the canyon just below Silverton the northerly and westerly dips of the Paleozoic formations are probably in large part related to the domal uplift of the Needle Mountains, which lie immediately to the south. Several miles farther south in the canyon the formations assume the westerly and southwesterly dips that prevail along the western flank of the Needle Mountains uplift.

The Telluride conglomerate and the younger volcanic formations rest upon an eroded surface of these older uplifts, as shown in Figure 12. Here, as at Ouray, the oldest volcanic formation is the San Juan tuff. This is overlain by several formations of the Silverton volcanic series.

The largest stock of intrusive rock found in the Silverton quadrangle is the quartz monzonite of the mountains immediately southwest of Silverton. Parts of it are exposed on the mountain slopes immediately north and south of Silverton, and the site of the town is eroded out of this rock. Unlike the quartz monzonite porphyry stock at Ouray, the Silverton stock cuts directly across both the sedimentary and volcanic formations and therefore belongs to the late Tertiary period of intrusive activity. The rocks adjacent to this quartz monzonite body are much indurated by contact metamorphism.

Ore deposits.—The following brief description of the ore deposits is restricted to a few typical examples of the fissure veins in the rocks of the Silverton volcanic series.

The larger and more persistent veins of the Silver Lake-Arrastre Gulch area (fig. 10) have northwesterly strikes and generally northeasterly dips, but they are not exactly parallel and tend to converge toward the southeast. The longer master fissures are commonly not simple breaks but consist of fracture zones repeatedly reopened, which in their mineralized parts may be called composite or compound veins. Both lead-silver ores and gold-bearing chalcopyrite ores compose the productive veins of both groups of fissures.

The Shenandoah-Dives vein, which occupies one of the major fissures of the northwesterly group, has been extensively mined,

mainly in its southeasterly part in the North Star (production \$2,000,000 [7]), Shenandoah-Dives (\$1,250,000 [7]), and Highland Mary mines. The veins of these mines occupy a fissure zone of northeasterly dip. In the Shenandoah-Dives the fissure zone is a fault of small displacement, with downthrow on the northeast, and contains an andesite dike from a few feet to 30 feet (9 meters) wide. The volcanic rocks close to the vein walls are largely replaced by quartz, sericite, carbonates, and pyrites. The ore of the Shenandoah-Dives group, the northwestern part of the vein, is characterized by more abundant chalcopyrite and pyrite, with the notable increase in gold content that is typical of the chalcopyrite ores of this district. The gangue is chiefly quartz with traces of manganiferous carbonates and some calcite and mixed carbonates as late veinlets. Bodies of massive galena ore occur here and there alongside or partly mixed with chalcopyrite ore. The proportion of metals in the ore is indicated by the ore mined in 10 months of operation and development work in 1928 and 1929, which averaged 0.32 ounce of gold and 5 ounces of silver to the ton (8.95 grams of gold and 139.95 grams of silver to the metric ton), with 0.7 per cent of lead and 1.4 per cent of copper.

The Sunnyside vein system is one of the largest and most productive of the Silverton region, and its ore differs from that of the veins just described. The outcrop was located in 1873, and the first work on it produced rich gold ore, which was soon exhausted. Later operations were concerned with attempts to concentrate the lower-grade ore, and several mills were run before the later large-scale operations of the United States Smelting, Refining & Mining Co. were started, in 1912.

The Sunnyside veins are very large, ranging from 20 to 80 feet (6 to 24 meters) in width. They have northeast, east-west, or northwest strikes and dip 65°–90° S. The veins are worked for over 7,000 feet (2,134 meters) of their length and through a vertical range of about 2,300 feet (701 meters). The principal ore minerals are galena, sphalerite, chalcopyrite, and pyrite in a gangue of quartz and rhodonite. Fluorite and calcite are abundant locally, and tetrahedrite, hübnerite, and native gold are less common. Hulin (18) has recognized three stages in the sequence of mineralization—an early stage of barren pyritic quartz veins, a stage of base-metal ores, and finally a stage of rhodonite veins and ribs. He states that "two of the most important shoots which have been developed are controlled by variation in strike of the vein fissure. Minor premineral cross faults modify these ore shoots to some extent."

[7] Net payments by smelters, according to C. A. Chase (7).

Although the early production of the Sunnyside mine consisted mainly in siliceous gold ores, the concentrates now produced by selective flotation are chiefly zinc concentrates and lead concentrates, but containing valuable amounts of silver and gold. The ore mined contains from 0.04 to 0.07 ounce of gold and 3 to 4 ounces of silver to the ton (1.12 to 1.95 grams of gold and 84 to 111.9 grams of silver to the metric ton), 0.5 per cent or less of copper, 3 to 4 per cent of lead, and 5 to 7 per cent of zinc.

Successive stages of mineralization.—In the chimney or stock deposits of the Red Mountain region and in some veins of similar mineralogy two very distinct stages in the mineralization have been recognized. The first stage consisted of silicification and the formation of barren quartz and pyrite, with widespread fumarolic and solfataric alteration of the country rock, accompanied by the dissemination of pyrite in altered rock. This

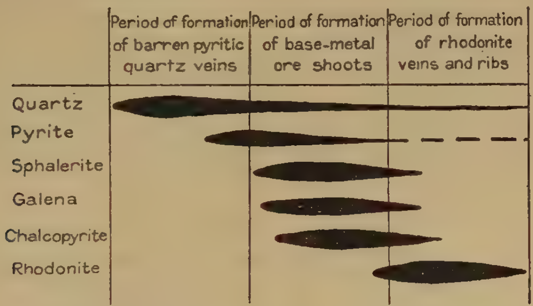


FIGURE 11.—Sequence of mineralization in Sunnyside mine. (After C. D. Hulin, Econ. Geology, vol. 24, fig. 5, p. 32, 1929)

stage failed to produce any appreciable concentration of valuable metals. It was followed with little or no overlapping by the deposition of sulphide ores with minor amounts of gangue. In the later ore stages silver was concentrated chiefly with the copper minerals. The galena ores appear to have formed separate portions of the ore shoots distinct from the copper ores, especially in the upper parts of the ore bodies.

A few of the fissure veins have been studied sufficiently to establish some of the main features of mineral succession. The succession in the Sunnyside vein as given by Hulin (18) is shown in Figure 11. The succession in the Camp Bird vein shows several periods which repeat in part the succession for the Sunnyside but with the addition of other distinct stages—(1) a period of base-metal ore and rhodonite with the early quartz, consisting of pyrite, sphalerite, galena, and chalcopyrite; (2) a

period of mixed carbonate formation with quartz and very minor amounts of most of the common sulphides, but chiefly chalcopyrite, sphalerite, and galena; (3) a period of quartz and adularia carrying free gold (forming the productive ore shoots of the Camp Bird mine); (4) a period of barren quartz. In the Camp Bird, as in the Sunnyside vein, there was an early deposition of pyrite and quartz, but this quartz is commonly coextensive with the base-metal vein. In the lower levels of the mine the early quartz is accompanied by much hematite. The richest gold ore is commonly but not invariably accompanied by adularia as well as quartz and belongs to stage 3. Fluorite, carbonates, and small amounts of sulphides are also products of stage 3.

In the veins of Silver Lake and Arrastre Gulch the formation of the quartz-pyrite-chalcopyrite ores appears in places to have been separated in time from the concentration of rich galena shoots. Where the separation is distinct a tendency is shown for the galena to concentrate in the central parts of the vein, as if it were of a later stage, as pointed out by Ransome (21). In other places galena and chalcopyrite ores are intimately mixed. The more common succession is possibly early quartz with succeeding pyrite-chalcopyrite-gold ores, followed with overlapping by galena ores, but this succession is certainly not invariable.

ROAD LOG—CONTINUED

From the road forks just below the town of Silverton the excursion takes the Durango road southwestward across the South Fork of the Animas River. The road climbs by a long switchback to the west side of the Animas Canyon, turns toward the south, and crosses exposures of the Sultan Mountain quartz monzonite intrusion (1.3 to 2.1 miles, or 2 to 3.4 kilometers).[8] Beyond the intrusive body the road follows the Upper Devonian shales (Elbert formation) and limestone (Ouray) to a point beyond Deadwood Gulch (2.5 miles, or 4 kilometers) where a stop is made to examine the Cambrian quartzite and basal conglomerate and pre-Cambrian schist. To the south, down the Animas Canyon, a view is obtained of the crest of the Needle Mountains. Figure 12 is a section across the canyon near this locality.

The road continues southward onto a high bench, passing exposures of the Devonian limestone and shale and Cambrian quartzite (Ignacio), and turns southwestward (3.8 miles, or 6.1 kilometers) across the Devonian formations and the Mississippian limestone (Leadville) to the red shales of the basal

[8] Distances from Silverton in this part of road log.

Pennsylvanian (Molas formation), following this formation to Molas Lake (altitude 10,488 feet, or 3,197 meters; 5.2 miles, or 8.4 kilometers). The mountains above this stretch of the road to the northwest afford an excellent view of the contact of the San Juan tuff and Telluride conglomerate resting on the Cutler formation (Permian).

Beyond Molas Lake the road crosses a flat-topped divide (altitude 10,900 feet, or 3,322 meters), turns westward, and descends a tributary stream of Lime Creek, entirely in the Hermosa formation. From the crest of the divide S. 70° W. a good view is obtained of Engineer Mountain (altitude 12,972 feet, or 3,954 meters), a high peak about 6 miles (9.6 kilometers) distant composed of the Pennsylvanian and Permian beds capped by a remnant of an early Tertiary sill of quartz trachyte porphyry.

Upon completing the descent to Lime Creek (11 miles, or 17.7 kilometers), where an irregular laccolithic body of granite porphyry has intruded the Hermosa formation, the road turns sharply south down the west side of Lime Creek. At about 12.3 miles (19.8 kilometers) the road crosses a fault contact between the Hermosa for-

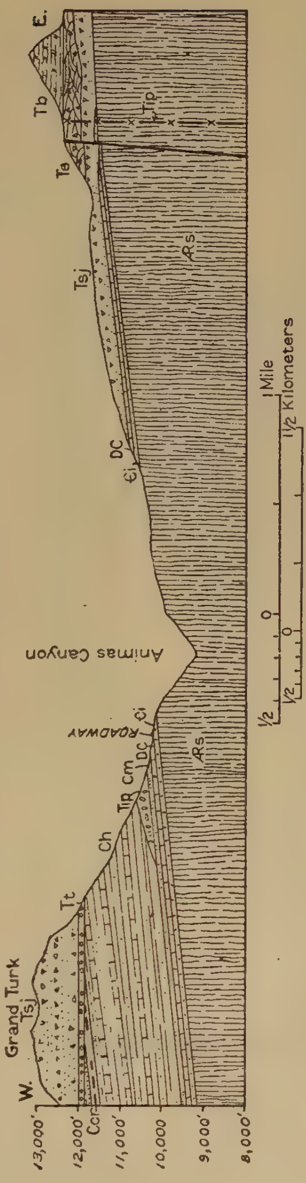


FIGURE 12.—Geologic section across the Animas Canyon 2½ miles (4 kilometers) south of Silverton. Tip, Intrusive porphyries; Tb, Burns latite; Te, Eureka rhyolite; Tsj, San Juan tuff; Tt, Telluride conglomerate; Ccr, Cutler and Rico formation (Permian); Ch, Hermosa formation (Pennsylvanian); Cm, Molas formation (Pennsylvanian); DC, Devonian and Mississippian limestones; Ꞓi, Ignacio quartzite; ARs, schist and gneiss. After Cross, Howe, and Spencer (13)

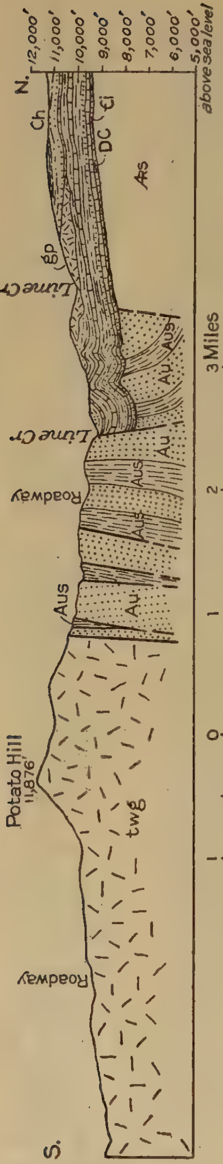


FIGURE 13.—Geologic section from the forks of Lime Creek south across Potato Hill. The route of the excursion winds back and forth across the line of the section, crossing it at the points marked "roadway." ARs, Archean schist; Au, Uncompahgre formation (quartzite); Aus, Uncompahgre formation (slate and shale); twg, Twilight granite (pre-Cambrian); Ꞓi, Ignacio quartzite; DC, Devonian and Mississippian limestones; Ch, Hermosa formation (Pennsylvanian); gp, granite porphyry intrusive in Hermosa. Folds in the Hermosa formation are generalized.

mation and the Algonkian quartzites (Uncompahgre formation), entering the edge of the pre-Cambrian uplift of the Needle Mountains. The road continues south across alternate bands of quartzite and slaty members of the Algonkian and finally descends again to the bottom of Lime Creek Canyon (15.5 miles, or 24.9 kilometers). Figure 13 is an interpretation of the structure at the north edge of the Needle Mountain uplift in the vicinity of Lime Creek.

Just before the road reaches the bottom of the canyon a fault contact between the quartzite and the Twilight granite is crossed. The mass of Twilight Peak (altitude 13,153 feet, or 4,009 meters), east of the canyon, and the lower mountains to the west are composed entirely of this granite, which is of pre-Cambrian age.

From Lime Creek the road climbs along a cut in the canyon walls of solid granite to the mountain spur between Lime Creek and Cascade Creek and then turns northwestward (18.7 miles, or 30.1 kilometers; altitude 9,550 feet, or 2,911 meters), descending by a winding route toward Cascade Creek, another tributary of the Animas River.

The road crosses a bridge over a small creek (21.4 miles, or 34.4 kilometers) at a turn, where the Cambrian quartzite and

overlying Devonian beds are exposed resting on the Twilight granite, and then crosses the edge of a lateral moraine to the canyon of Cascade Creek (22.7 miles, or 36.5 kilometers). In this canyon the Devonian and Mississippian limestones are exposed near the bridge and the Cambrian beds farther down.

Turning sharply across the bridge at Cascade Creek, the road climbs to a bench above the canyon and continues southward at the foot of the Hermosa Cliffs, an escarpment which bounds the Needle Mountain uplift on the west. This scarp is composed of the westward-dipping Hermosa formation (Pennsylvanian), and the bench on which the road is built is part of an old valley bottom of early Quaternary time, underlain by the Devonian and Mississippian limestones and the Molas formation. There are numerous patches of old alluvial flats still remaining on this bench.

After passing the break at the east fork of Hermosa Creek (25.2 miles, or 40.5 kilometers) the escarpment continues due south for 10 to 12 miles (16 to 19 kilometers). The bench to the east of the Hermosa Cliffs ranges from 2 to 3 miles (3.2 to 4.8 kilometers) in width, but the road keeps near the foot of the cliffs on a small upper bench formed by the Paleozoic limestones. The modern Animas Valley, which bounds the main bench on the east, is hardly noticeable from the road, but the river has cut a canyon in the pre-Cambrian granite and schist from 1,000 to 2,500 feet (305 to 762 meters) below the surfaces of this old valley and the upland to the east.

A view from this point eastward across the Animas Canyon shows the southwestward-sloping mesas of lower Paleozoic beds that form the southern slopes of the Needle Mountains. Figure 14 illustrates the geologic structure from these mesas across the Animas Canyon to the Hermosa Cliffs.

Approaching the south end of the Hermosa Cliffs the road turns to the southeast and descends from the bench at the foot of the cliffs, crosses the railroad (38.2 miles, or 61.5 kilometers), and goes down to Pinkerton Hot Springs (39.8 miles, or 64.1 kilometers), in the valley of the Animas River.

At Pinkerton Hot Springs the Devonian and Mississippian limestones dip southward beneath the valley, and thence down the valley to a point just below Trimble (44 miles, or 70.8 kilometers) the lower valley slopes are composed of the Hermosa formation.

Down the valley from Trimble views are obtained of the higher formations as their southward dip carries them successively beneath the level of the valley—at 47.5 miles (76.4 kilometers) the Triassic red beds; at 49.4 miles (79.5 kilometers) the white Jurassic sandstone (Entrada sandstone); and at 50.5 miles

(81.3 kilometers) the Morrison and Dakota (?) formations, with the terminal moraine of the Wisconsin glacier stretching across the valley just above the town of Animas (51 miles, or 82 kilometers).

At 52.4 miles (84.3 kilometers) the road crosses the Animas River into the city of Durango (altitude 6,520 feet, or 1,987 meters).

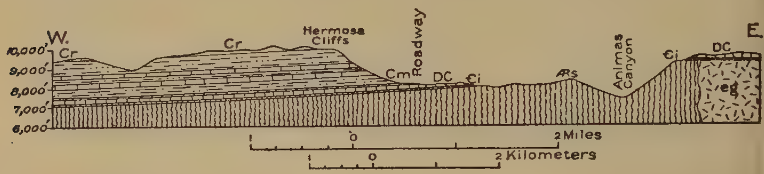


Figure 14.—Geologic section from slope south of the Needle Mountains west across the Animas Canyon to the Hermosa Cliffs, about a mile (1.6 kilometers) south of the Ignacio Reservoir. ARs, Archean schist; eg, Eolus granite (Cambrian?); Ꞓi, Ignacio quartzite (Cambrian); DC, Elbert formation (Devonian), Ouray limestone (Devonian), and Leadville limestone (Mississippian); Cm, Molas formation (Pennsylvanian); Ch, Hermosa formation (Pennsylvanian); Cr, Rico formation (Permian). After Cross (10)

SAN JUAN BASIN

Durango stands on the north rim of a large basin that occupies a portion of northwestern New Mexico and southwestern Colorado. The dimensions of the basin are 125 miles (201 kilometers) north and south and 100 miles (161 kilometers) east and west, and somewhat less than one-third of it is within the State of Colorado. The southern third of this basin is occupied by nearly flat-lying rocks of the Mesaverde group; the northern two-thirds is occupied chiefly by inward-dipping formations ranging from Mesaverde to Wasatch, forming a closed structural basin.

The region in which the basin is situated is typical of the semiarid Southwest except that its north rim, near the foothills of the San Juan Mountains, receives somewhat greater rainfall than other parts of the basin.

STRATIGRAPHY

An abbreviated description of the sedimentary formations found in the northwestern part of the basin, in Colorado, is included in the accompanying table, based upon detailed descriptions by Reeside (22).

No important break is found in the Upper Cretaceous sedimentary series in the beds from the Mancos shale to the top

A. PORTION OF THE NORTH ESCARPMENT OF MESA VERDE

B. CLIFF HOUSE SANDSTONE AND SPRUCE TREE HOUSE

Cretaceous and Tertiary formations of the western part of the San Juan Basin in Colorado

System	Series	European equivalents	Formation	Character	Thickness	
					Feet	Meters
Tertiary.	Eocene.	Ypresian. Sparnacian.	Wasatch formation.	Massive gray to brown conglomeratic sandstone interbedded with variegated shale. Fluviatile. Contains remains of mammals and plants.	1,000±	305±
		Thanetian.	Torrejon and Puerco formations undifferentiated.	Lenticular gray to brown conglomeratic sandstone interbedded with shale. Fluviatile. Contains remains of mammals, reptiles, fish, and plants.	0–1,450	0–442
			—Unconformity—			
Tertiary (?).	Eocene (?).	Montian.	Animas formation.	At base, coarse beds with weathered and waterworn andesitic débris and pebbles of siliceous rocks. Remainder of formation shale and sandstone with andesitic débris and beds of fine conglomerate. Fluviatile. Dinosaur and plant remains.	0–2,670	0–814
			—Unconformity—			
Cretaceous (?).	Upper Cretaceous (?).	Maestrichtian (?).	McDermott formation.	In the north, andesitic tuff and tuffaceous sandstone and shale, with some conglomerate of siliceous rocks. Proportion of volcanic material decreases southward. Contains plants and reptilian remains.	0–300	0–91
			—Local unconformity—			
Cretaceous.	Upper Cretaceous.	Maestrichtian.	Kirtland shale.	Consists of upper and lower shale members, and middle sandstone member. Fluviatile. Contains reptilian and fish fossils and plants.	565–1,325	172–404
			Fruitland formation.	Gray sandy shale, gray-white cross-bedded sandstone, brown indurated sandstone, carbonaceous shale, and coal. Fresh and brackish water origin. Reptilian, fish, and invertebrate fossils and plants.	340–530	104–162
			Pictured Cliffs sandstone.	Buff to light-yellow and gray sandstone interbedded in the lower part with thin gray shale. Marine. Invertebrate fossils.	125–240	38–73
		Campanian.	Lewis shale.	Greenish-gray and dark-gray sandy shale with a few lenses of brown sandy limestone and buff concretions. Marine. Invertebrate fossils.	1,710–2,290	521–698
			Mesaverde group. Cliff House sandstone.	Yellow to red-brown sandstone with some sandy shale. Some beds massive, cliff-forming. Marine invertebrates.	90–390	27–119
			Mesaverde group. Menefee formation.	Gray shale with some sandstone and coal. Of fresh and brackish water origin, with a few marine beds.	270–360	82–110
			Mesaverde group. Point Lookout sandstone.	Massive buff or cream-colored to red-brown sandstone. Marine.	60–270	18–82
		Santonian. Coniacian. Turonian.	Mancos shale.	Dark-gray and drab sandy shale, with a few sandstone lenses. Contains marine invertebrates.	1,800–2,000	549–610
		Cenomanian (?).	Dakota (?) sandstone.	Brown sandstone with some shale lenses and coal; cherty conglomerate at base.	200–250	61–76

of the McDermott formation (Cretaceous?), as the changes in the marine beds were caused by shifts in the shore line, and the changes within the McDermott formation were local and not sharp.

The andesitic tuffs and tuffaceous sandstones and shales comprising the McDermott formation rest with local unconformity upon the Kirtland shale and mark the beginning of the long period of volcanic activity. The Animas formation, which overlies the McDermott and also contains much volcanic débris, locally overlaps the McDermott formation, the Kirtland shale, and part of the Fruitland formation. This relation of the Animas formation, caused by tilting of the underlying beds, indicates that notable crustal disturbances were occurring in connection with the volcanism in neighboring parts of the San Juan area to the north. The absence of volcanic material in the later sediments of the basin, as the Torrejon and Wasatch, indicates that volcanism was dormant in the near-by area during later Eocene time. Possibly by the time represented by the lower Wasatch beds of the San Juan Basin all the volcanic accumulations in the adjacent parts of the San Juan Mountain area had been destroyed and transported into basins of sedimentation.

MESA VERDE

Mesa Verde is the name given, probably by the Spanish explorers, to a cuesta of the Upper Cretaceous coal-bearing rocks that form a part of the north rim of the San Juan Basin about 35 miles (56.3 kilometers) west of Durango. The northern escarpment of the Mesa Verde rises from 1,500 to 2,000 feet above the Colorado Plateau to the north, and its much dissected mesalike surface slopes southward with the underlying formations to the lower plateaus of northwestern New Mexico, bordering the San Juan River.

The origin of the Mesa Verde structure is related to the forces that caused the uplift of the San Juan Mountains and the downwarping of the San Juan Basin, and its unique physiographic features have been produced by the headward erosion of its many southward-leading canyons and the southward retreat of its northern escarpment by the wearing away of the soft underlying shales of the marine Upper Cretaceous (Mancos shale). A view of a part of the northern escarpment is shown in Plate 7, *A*. In late Tertiary time the mesa surface was probably coextensive with peneplaned surfaces covering parts of the southwestern San Juan Mountains and the neighboring Colorado Plateau. Uplift and further doming of the San Juan

Mountain area was attended by a slight tilt of the surrounding plain, and renewed erosion readily reduced the more exposed areas of softer rocks, so that now only remnants of the harder formations remain as mesalike uplands.

At the northeastern edge of the Mesa Verde the cliffs at the top of the escarpment are formed by the Point Lookout sandstone, the lower marine formation of the Mesaverde group. However, in the northern part of the Mesa Verde the beds dip southward at a somewhat greater rate than the surface of the mesa, so that the overlying Menefee formation and Cliff House sandstone successively constitute the surface formations southward down the slope of the mesa. At Spruce Tree House, about 7 miles (11.2 kilometers) south of the escarpment, the surface and the canyon walls are formed of the Cliff House sandstone, so named from the large numbers of ancient dwellings built in the natural caves formed above shaly partings or in softer layers beneath massive cliff-making sandstones.

The heads of some of the main canyons and many of the tributary canyons are boxlike, their headward erosion evidently being aided by undercutting of the sandstones by the process of differential weathering. The seepage of underground water along shale partings appears to have assisted in weakening certain layers of the sandstone. Many of the longer canyons reach the north edge of the mesa, where they have been literally beheaded by the southward retreat of the escarpment. Excellent examples of this feature are seen along the Government road at the northeastern edge of the Mesa Verde, especially at Morefield and Prater Canyons.

The surface of the mesa supports a growth of cedar and piñon, as well as grass and small plants, but the region is arid. The inaccessibility of the mesa was clearly its attraction as a home for the early Indian tribes of the Southwest. Although the habitations and temples of the cliff dwellers are the most striking archeologic objects on the mesa (pl. 7, *B*), there is also evidence of even older occupations of the region by the basketmaker Indians. Further information on the archeology of the region is given in the pamphlet on the Mesa Verde National Park issued by the National Park Service.

ROAD LOG—CONTINUED

The city of Durango is situated upon one of the terrace remnants of the Wisconsin outwash plain, which is underlain by the Mancos shale. To the east of the city, about 300 feet (91 meters) above the valley bottom, may be seen the bench that represents the outwash level of the Durango glaciers, the ter-

minal moraine of which lies on the northern part of this bench about a mile farther downstream than the Wisconsin moraine seen at Animas.

The highway to Mesa Verde leaves Durango toward the west, crossing the Animas River (0.4 mile, or 0.6 kilometer[9]), from which a view is obtained downstream of the Durango smelter of the American Smelting, Refining & Mining Co.

Above the Durango smelter and to the south (left) of the road is the escarpment formed by the sandstones of the Mesaverde group. The road continues behind the Mesaverde hogback for about 2 miles (3.2 kilometers) and then turns southwest across a bridge (2.6 miles or 4.2 kilometers) and goes up the valley which has been cut through the escarpment. Some coal-mine workings in the Mesaverde are visible above the road level.

About a mile beyond Porter (4.5 miles, or 7.2 kilometers) the road passes by outcrops of a series of alternating thin sandstones and shale beds marking the transition to the Lewis shale, which overlies the upper (sandstone) formation of the Mesaverde group.

At the forks of the road (6.8 miles, or 10.9 kilometers) the route turns northwestward through low hills of Lewis shale capped with early Pleistocene terrace gravel. After crossing the railroad (10.4 miles, or 16.7 kilometers) on the less dissected flat top of the gravel plain, the road approaches the edge of the La Plata River Valley, where a view is obtained of the La Plata Mountains to the north and northwest.

The descent of 150 to 200 feet (46 to 61 meters) into the La Plata Valley is made, and the road is followed up the valley to Hesperus (12.5 miles, or 20.1 kilometers). Continuing northwestward the road completes the recrossing of the Mesaverde deposits and follows the railroad to the head of the Cherry Creek Valley, in the Mancos shale. A good view is obtained of the upturning of the formations along the south flanks of the La Plata Mountains.

At the start of the descent into Cherry Creek Valley (15.2 miles, or 24.5 kilometers) the road leaves the railroad and then follows down the north side of the valley, which is eroded entirely in the southward to southwestward dipping Mancos shale below the Mesaverde cuesta. A geologic section from the slopes of the La Plata Mountains southward across the road at this locality is represented in Figure 15.

Leaving Cherry Creek the road turns sharply north (22 miles, or 35.4 kilometers) and then switches back southwestward,

---

[9] Distances from Durango given in this part of road log.

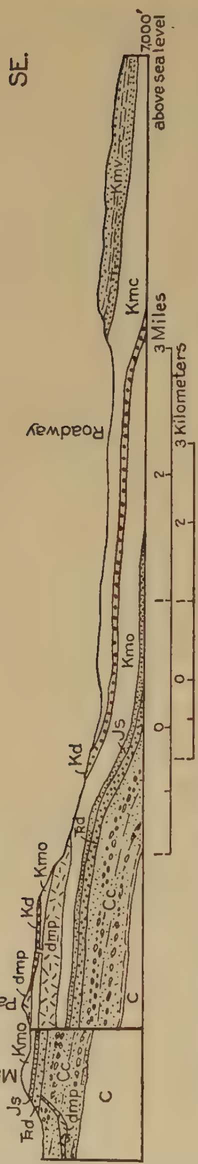


FIGURE 15.—Geologic section from the La Plata Mountains southeast, about 1 mile (1.6 kilometers) west of the La Plata River. After Cross and Spencer (16), with some changes in formation names. C, Carboniferous formations, Pennsylvanian and older; Cc, Cutler formation (Permian); ℞d, Dolores formation (Upper Triassic); Js, Jurassic sandstone; Kmo, Morrison formation (Cretaceous?); Kd, Dakota (?) sandstone (Upper Cretaceous); Kmc, Mancos shale (Upper Cretaceous); Kmv, Mesaverde group (Upper Cretaceous); dmp, diorite porphyry and monzonite porphyry (probably Eocene)

climbing toward Menefee Mountain, which is capped by the coal-bearing Menefee formation of the Mesaverde group.

The crest of the divide (25 miles, or 40.2 kilometers; altitude 8,059 feet, or 2,456 meters), east of Menefee Mountain, is flat-topped, underlain by Mancos shale, and covered by high terrace gravel of early Quaternary age. From the edge of this divide one may look westward across the Mancos Valley to Point Lookout, the northeast extremity of the Mesa Verde National Park, with the intrusive body of Ute Mountain beyond at a distance of about 35 miles (56.3 kilometers). The road descends into the valley of the Mancos River (30 miles, or 48.3 kilometers) and follows its south bank, crossing the river (32.3 miles, or 52 kilometers) into the town of Mancos.

Leaving Mancos the road goes due west over the late outwash gravel on which the town is built and then turns southwestward at the low hills of Mancos shale and crosses a small tributary of the Mancos River (36 miles, or 58 kilometers) flanked by gravel-covered flats and low hills of Mancos shale.

At 39.8 miles (64 kilometers) the route leaves the through highway and goes south toward Point Lookout, to begin the ascent to the top of the Mesa

Verde by the Government road. After climbing the east slope of Point Lookout the base of the Point Lookout sandstone is reached near the road cut through the ridge (42.7 miles, or 68.7 kilometers). The road then turns down into Morfield Canyon and crosses to the face of the north escarpment. The cutting off of the head of Morfield Canyon by the retreat of this escarpment is strikingly shown. The same phenomenon is also seen at the head of the next canyon, Prater Canyon, where the road leaves the north scarp (45 miles, or 72.4 kilometers).

From Prater Canyon to the point where the road turns south down the Mesa Verde, it winds across the alternate ridges and valleys close to the north escarpment, largely in the Menefee formation. At about 52 miles (83.6 kilometers) the road turns south and descends along the narrow upland surface of Chapin Mesa to the Government park headquarters near Spruce Tree House (58.9 miles, or 94.8 kilometers; altitude 6,930 feet, or 2,112 meters).

RICO DISTRICT

By E. T. McKnight

The Rico Mountains are a group of peaks occupying a roughly circular area, 12 to 15 miles (19 to 24 kilometers) across, that lie to the southwest of the main San Juan group. They are the erosion remnants of a low structural dome that has been deeply dissected. The rocks involved in the doming range from pre-Cambrian to Jurassic. The Rico mining district is located in the core of the dome, where the older rocks of the region are exposed. Although the greatest factor involved in exposing these more ancient rocks has undoubtedly been the downward cutting of the Dolores River, which traverses the mining district from north to south, part of the effect has also been produced by upthrust faulting in the center of the dome. The upthrusting is apparently related to a stock of monzonite whose apex is revealed in an oblong outcrop, about 2 miles (3.2 kilometers) long from east to west and three-quarters of a mile (1.2 kilometers) wide from north to south, lying immediately west of the Dolores River at Rico. Dikes and sills of monzonite porphyry are bedded in the sedimentary series in the center of the dome, and though they are earlier than the central stock, they are evidently from the same magmatic source.

The oldest sedimentary rocks crop out in the valley, chiefly east of the river, in an upthrust fault block that lies in line with the trend of the igneous core. These rocks are pre-Cambrian schists, pre-Cambrian and probably also Cambrian quartzites, and Devonian limestones and quartzites. Rocks of Pennsylvanian (Hermosa) age also crop out in the central block but

are much more prominently exposed in the slopes of the mountain above the town, where, although faulted in numerous places by breaks of the same type as those that bound the more central block, they owe their present position more to upward doming of the rocks at the center of the dome.

The main production of the district has come from the northeast, east, and southeast sides of the central igneous core, and over half of it was obtained from the hill immediately southeast of Rico. The most productive ore deposit was developed as a blanket vein in the lower part of the Hermosa formation at a horizon where a bed of sedimentary gypsum, originally 15 to 30 feet (4.5 to 9 meters) thick, in a series of shales, sandstones, and limestones, had previously been dissolved out, probably by the ore solutions, to leave a brecciated zone, ideally fitted as a site for the deposition of ores. The ore solutions were admitted through a series of northeastward and northwestward trending fissures that traverse the rocks below the blanket. The northeasterly fissures were themselves productive, as lode deposits, to depths of 150 feet (46 meters) below the blanket, below which they contained little in addition to the worthless quartz and pyrite gangue.

Production began in 1879, became of importance in 1889, and continued so through 1894, with a total gross calculated value for gold, silver, copper, and lead from 1879 to 1894 of $9,051,540, of which $6,973,910 represented silver. Beginning in 1893, zinc also was recovered. In 1913 and 1917 the output in terms of recovered metals exceeded $500,000 each, the highest yearly records between 1898 and 1926. The records for 1926, 1927, 1928, and 1929 ranged from $990,000 to $1,448,000.

The ores are very complex. The silver-bearing minerals are argentite, proustite, polybasite, and argentiferous tetrahedrite, but the more abundant ore minerals are galena, sphalerite, chalcopyrite, and pyrite. The dominant gangue minerals are quartz and rhodochrosite.

A recent (1924–1929) renewal of operations in the district was brought to an end in 1929 by the collapse of the metal market. In this work more attention was given to the northeast side of the monzonite core, in the hill a mile or so north of Rico, where the ore bodies have been largely formed by the replacement of limestone beds by massive galena, sphalerite, and pyrite.

It has been estimated that about 40 miles (64 kilometers) of underground tunnels have been driven in the exploitation of the Rico district since the beginning of its development. The total production of the district from 1879 through 1930, in terms of recovered metals, has been $2,035,968 in gold, 12,678,130 ounces (394,333,960 grams) of silver, 7,955,339 pounds (3,608,485 kilo-

grams) of copper, 72,095,285 pounds (32,701,900 kilograms) of lead, and 45,665,116 pounds (20,713,352 kilograms) of zinc, with a total gross calculated value, at average yearly prices for each metal, of $20,184,985.

BIBLIOGRAPHY FOR EXCURSION 1

1. Atwood, W. W., and Atwood, R. S., Physiographic stages in the evolution of the San Juan Mountain region and their correlation with the physiography of the Front Range of Colorado [abstract]: Assoc. Am. Geographers Annals, vol. 15, No. 1, p. 31, 1925.

2. Atwood, W. W., and Mather, K. F., The evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colorado: Jour. Geology, vol. 20, pp. 385–409, 1912.

3. Atwood, W. W., and Mather, K. F., A geographic study of the Mesa Verde (Colorado): Am. Geog. Soc. Bull. 44, pp. 593–598, 1912.

4. Atwood, W. W., and Mather, K. F., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, pp. 13–26, 1915.

5. Atwood, W. W., and Mather, K. F., The physiography and Quaternary geology of the San Juan Mountains, Colorado: U. S. Geol. Survey Prof. Paper 166, 1932.

6. Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district of Colorado, and its bearing on ore deposition: Colorado Sci. Soc. Proc. vol. 12, pp. 151–232, 1930. A restudy of this district shows two widely separated periods of intrusive activity and mineralization. Gives reasons for dating these as late Cretaceous (or early Eocene) and Miocene. Also revises stratigraphy and structure of earlier investigators.

7. Chase, C. A., A geological gamble in Colorado meets with success: Eng. and Min. Jour., vol. 128, No. 6, pp. 202–205, Aug. 10, 1929.

8. Coffin, R. C., Radium, uranium, and vanadium deposits of southwestern Colorado, Colorado Geol. Survey Bull. 16, 1921. General structure, stratigraphy, and geology of the region bordering Utah in the southwestern part of Colorado.

9. Collier, A. J., Coal south of Mancos, Montezuma County, Colorado: U. S. Geol. Survey Bull. 691, pp. 293–310, 1919.

10. Cross, Whitman, and Hole, A. D., U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), 1910.

11. Cross, Whitman, Howe, Ernest, and Irving, J. D., U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), 1907.

12. Cross, Whitman, Howe, Ernest, Irving, J. D., and Emmons, S. F., U. S. Geol. Survey Geol. Atlas, Needle Mountains folio (No. 131), 1905.

13. Cross, Whitman, Howe, Ernest, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), 1905.

14. Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), 1899.

15. Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), 1905.

16. Cross, Whitman, Spencer, A. C., and Purington, C. W., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.

17. Henderson, C. W., Mining in Colorado [a history of discovery, development, and production]: U. S. Geol. Survey Prof. Paper 138, 1926.

18. Hulin, C. D., Structural control of ore deposition: Econ. Geol. vol. 24, pp. 15–49, 1929. Diagram of sequence of mineralization, Sunnyside mine, p. 32. Statements regarding structure of Sunnyside vein, pp. 38, 39.

19. Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colorado: U. S. Geol. Survey Bull. 510, 1917.

20. Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 745–848, 1898.

21. Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colorado: U. S. Geol. Survey Bull. 182, 1901.

22. Reeside, J. B., Jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin of Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 134, pp. 1–70, 1924. Stratigraphy of the region bordering the San Juan Mountains on the southwest.

23. Weeks, H. J., Oil and water possibilities of parts of Delta and Mesa Counties, Colorado: Colorado Geol. Survey Bull. 28, 1925.

MINTURN TO FLORISSANT

INTRODUCTION

By T. S. Lovering

Excursions 2 and 3 go southeast from Minturn to Colorado Springs, crossing the southern part of the Park Range system and the Front Range. (See pl. 8.) They pass through the most productive zinc, lead, silver, and gold districts of Colorado, and excursion 2 will be devoted chiefly to a study of the mining and economic geology. The paleontology, stratigraphy, and structure of this region are also of great interest, and on excursion 3 these phases of the geology will be emphasized, and opportunities will be given to collect fossils from most of the Paleozoic and Mesozoic formations and from the Miocene lake beds at Florissant.

Minturn is on the southwest side of the northwestward-trending Gore Range, which is the southeasterly extension of the Park Range of Wyoming and northern Colorado. Farther south, near Leadville, the southern continuation of the Gore Range is called the Mosquito Range. They are separated by transverse valleys, but there is no structural break between them and they may be regarded as a unit. The wide northwestward-trending valley of the Blue River separates the Front Range from the Gore Range and the northern part of the Mosquito Range. The Mosquito Range and the Front Range are connected by high east-west spurs at Hoosier Pass, but farther south they are separated by the broad north-south basin of South Park. The Gore and Mosquito Ranges form a relatively narrow uplift, being in only a few places more than 10 miles (16 kilometers) wide. In marked contrast, the Front Range is from 35 to 45 miles (56 to 72 kilometers) wide in this region.

The geologic section includes pre-Cambrian schists, gneisses, and granites; Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, Permian, Lower Cretaceous, Upper Cretaceous, early Eocene, Miocene, and Pleistocene sediments; early Eocene

and Miocene intrusive rocks; and Miocene extrusive rocks. The formation names and the general character, thickness, and age of the different units are shown in Plate 8.

The route followed from Minturn to Fairplay is in a region close to the western border of the ancient Front Range highland and is characterized by marked overlaps of some of the formations. The Pennsylvanian and Permian rocks transgress much farther onto the pre-Cambrian rocks of the Front Range highland than the earlier Paleozoic formations, but it is unlikely that they ever completely covered the ancient land mass. During Cretaceous time, however, this old land was completely covered by marine sediments.

The Gore and Mosquito Ranges and the western part of the Front Range northwest of Hoosier Pass are steep or overturned asymmetric folds broken by strike faults that have dropped the southwest side. The two largest faults of the region—the Williams Range underthrust fault, on the western border of the Front Range, and the Mosquito fault, on the western edge of the Mosquito and Gore Ranges—are more than 50 miles (80 kilometers) long. The steeply dipping Mosquito fault shows a vertical movement of about 5,700 feet (1,737 meters) northeast of Minturn, and the gently dipping Williams Range underthrust fault has a horizontal displacement of more than 4 miles (6.4 kilometers) east of Dillon. All the major faults of the region extend northwest, and minor parallel faults are also common, especially near Leadville.

A belt of ground from 5 to 25 miles (8 to 40 kilometers) wide which is characterized by much fracturing and many early Eocene porphyritic intrusions and which contains most of the mineral deposits of the Front Range and Mosquito Range extends northeastward across the somewhat earlier northwest folds and faults in this region. Because of the metalliferous deposits that are localized in this northeasterly strip, it is known as the "mineral belt." Northeastward-trending faults and veins are much more common in the mineral belt than in the regions northwest and southeast of it. Near Leadville the mineral belt is about 30 miles (48 kilometers) wide, but it narrows northeastward across the Front Range toward Boulder. Almost all the porphyritic rocks of the mineral belt are of early Eocene age, but in the Front Range farther south many porphyritic volcanic and intrusive rocks of Miocene age are present. The gold telluride deposits of Cripple Creek, the most productive gold district in Colorado, are associated with a Miocene volcanic vent and will be visited by excursion 2.

The major folding of the Rocky Mountains in Colorado occurred early in Eocene time, and ever since the land has been

undergoing erosion. By the end of Eocene time a gently undulating surface known as the Flattop peneplain had been developed, and it is now preserved above an altitude of about 12,000 feet (3,657 meters) in the nearly level summits of the mountains bordering the north end of South Park. Uplift and rejuvenation of the streams in Miocene time caused the formation of a marked bench at the edge of the mountains that slowly worked its way inward during the Miocene and Pliocene epochs, destroying the earlier peneplain as it encroached upon it. This surface, which is known as the Rocky Mountain peneplain on the east side of the Front Range, is well shown on the east side of South Park, about 2,000 feet (610 meters) below the Flattop peneplain. Glaciation accompanied a marked uplift of the mountains early in the Pleistocene epoch. Remnants of the valley floors cut by the early ice can be seen at many places, notably in the region near Alma and Leadville. Depositional surfaces formed by the outwash from the early glacial stage are conspicuous features both in the region near Leadville and in South Park and stand up as high terraces well above the present valley bottoms. The deep valleys cut by the ice during the last glacial stage and the extensive low-lying terraces built by the outwash from the last glaciers are conspicuous features of the landscape in the region between Minturn and Fairplay.

ROAD LOG

As excursions 2 and 3 cover nearly the same ground from Minturn to Florissant, only one road log is given for both excursions for that part of the route. The places of divergence from the main route are noted in the body of the log, and the side trips are indicated in parentheses.

From Minturn the road leads southeastward for 2 miles (3.2 kilometers) over the gravel outwash and morainal material deposited by a large valley glacier that flowed northward from Holy Cross Mountain. These deposits have forced the Eagle River against its east bank, where it undercuts the Weber (?) formation. At 3 miles (4.8 kilometers) a postglacial valley (Two Elk Creek) enters from the east, showing a sharp contrast with the moraine-flanked valley just mentioned. Here also the eastward, down-dip, monoclinal shifting of the Eagle River is well displayed in a southward view. All the rocks exposed in the cliffs east of the river, except the very top of the section, are of Pennsylvanian age. The lenticular form of some of the more massive sandy layers is notable.

At 2.3 miles (3.7 kilometers) the road swings to the left, crosses the stream, and commences to rise above a rocky gorge cut in the pre-Cambrian and lower part of the Paleozoic section.

(Excursion 3 turns right on the main road after crossing the Eagle River and passes through the Leadville limestone for one-fifth of a mile (0.3 kilometer). Across the valley at the right are good exposures of gray and red Pennsylvanian shales and sandstones in a high cliffy hill. At 3.2 miles (5.1 kilometers), near a curve in the road, the railroad bridge at the right leads across the Eagle River to the upper part of the Pennsylvanian section. At 3.55 to 3.6 miles (5.7 to 5.8 kilometers), at a curve in the road, nearly vertical shales containing Permian plants crop out.)

At 4 to 5.5 miles (6.4 to 8.9 kilometers) the highway is cut in a cliff of Leadville limestone. Quartzite that is considered to be of Upper Devonian age is exposed at a sharp curve in the road. At 5.6 miles (9 kilometers) the quartzite layer at the base of the Mississippian Leadville limestone crops out; a sideritic rock formed by the replacement of this limestone and the so-called "zebra limestone," a dark-gray and white banded phase, is exposed a short distance beyond. At 5.7 miles (9.2 kilometers) a monzonite porphyry sill at the top of the Leadville limestone is well shown. Gilman is entered at 6.1 miles (9.8 kilometers).

The ore deposits at Gilman are the largest zinc deposits in the State of Colorado and among the largest in the United States. Excursion 2 will stop at Gilman to visit the mines of the New Jersey Zinc Co. A brief description of the district is given below.

BATTLE MOUNTAIN (RED CLIFF, GILMAN) MINING DISTRICT

By T. S. Lovering and Charles H. Behre, Jr.

Formations.—The oldest rocks in the Gilman district (pre-Cambrian) are northeastward-dipping schists bearing conspicuously quartz, biotite, and sillimanite; mica gneiss; granite gneiss; quartz diorite gneiss; and some marble and quartzite. The schists and gneisses alternate and grade into each other and, near the borders of certain granite masses, into injection gneiss. The metamorphic rocks are chiefly confined to the region west of the Eagle River. Masses of pink medium-grained pre-Cambrian granite cut the metamorphic rock and are well exposed in the bottom of the Eagle River Valley. Small areas of quartz monzonite have been found in the granite and are apparently contemporaneous. Gray pre-Cambrian quartz diorite is cut by the granite in the Eagle River Valley about half a mile (0.8 kilometer) west of Red Cliff.

The Paleozoic rocks have a monoclinal northeasterly dip, and the course of the Eagle River is approximately that of the con-

tact between the older pre-Cambrian rocks and the Sawatch quartzite, of Upper Cambrian age. Because of the regional structure, the pre-Cambrian rocks occupy most of the area southwest of the Eagle River, although many of the gently sloping divides are capped by the resistant Sawatch quartzite. The outcrop of the Ordovician and Mississippian rocks is restricted to the northeast wall of the steep-sided valley of the Eagle River. A short distance northeast of the river most of the region is covered by Pennsylvanian sediments.

The ore deposits are found only in the pre-Pennsylvanian rocks, and the thick series of gray-black and reddish shales, micaceous sandstones, grits, and dark-colored limestones of Pennsylvanian age are economically unimportant. The general character of the earlier formations is shown in the table given on page 71.

Formations in the Gilman district

Age	Formation	Thickness		Character of rocks
		Feet	Meters	
Permian	Maroon formation	4,000+	1,219+	Chiefly limestone, conglomerate, and sandstone; gray to buff; contains some quartzite near the base.
Pennsylvanian	Weber (?) formation	1,500±	457±	Red to reddish-brown conglomerate and sandstone with subordinate shale, grading downward into black and gray shale, sandstone, and limestone near the base.
Early Eocene	Gray porphyry	50	15	Quartz monzonite porphyry sill.
Mississippian	Leadville limestone	143	44	Dolomitic limestone, from light gray to almost black; contains irregular layers and masses of "zebra limestone" and black chert nodules and stringers. Basal bed is sandy, gritty quartzite.
Devonian	Chaffee formation	117	36	Chiefly light to dark gray fine-grained dolomitic limestone, 77 feet (23 meters). Parting quartzite member, coarse gritty white quartzite with 2-foot (0.6-meter) basal bed of white conglomerate, 40 feet (12 meters).
Ordovician	Harding sandstone	45	14	Red and green sandy shales alternating with dolomitic sandstone in the upper part, overlying white cross-bedded quartzite and soft white sandstone and gray quartzitic grit.
Ordovician	Manitou limestone	18	3	Thin white gritty quartzite overlying red-brown thick-bedded dolomite.
Upper Cambrian	Sawatch quartzite	286	87	Upper part comprises alternating beds of light to tan sandstone, sandy shale, light-gray dolomite, and greenish-gray fossiliferous shale, overlying a massive buff dolomite blotched with dark-red, brown, and purplish markings, known as "red cast beds." Lower part of formation consists of white to gray limy sandstone alternating with white to pinkish quartzite.
				Massive to thin-bedded, hard, white or gray, sandy and gritty quartzite, conglomeratic near the bottom.
Algonkian (?)		(?)	(?)	Schist, gneiss, granite, and diorite.

Structural geology.—The Paleozoic sediments dip 5°–15° NE. throughout the Gilman district. Until recently no faults of large displacement have been recognized in the district, but steep northeastward-trending faults of small throw are common. There are also thrust faults, whose planes are nearly parallel to the bedding. Along many of the faults the amount of crushing and gouge is out of proportion to the small displacement, and it is believed that their walls have moved back and forth. The low-angle thrust faults and northeasterly faults are earlier than the ore, but there are a few northwesterly faults that may be later than the ore. The maximum displacement noted on the cross-breaking faults is 30 feet (9 meters).

Ore deposits.—The primary ores were deposited in early Eocene time and in part oxidized during late Tertiary and Pleistocene time. Two types of ore deposits are present—fissure veins in the pre-Cambrian rocks and the Sawatch quartzite and replacement deposits in the Leadville limestone and, to a minor extent, in the underlying rocks.

The ore shoots in the fissure veins occur where the rocks have been sufficiently fractured to permit easy access of ore solutions. Openings of this type are more common in the stronger and more brittle rocks, and thus the fissure veins are largely confined to the pre-Cambrian rocks and the Cambrian quartzites.

The veins are from 1 to 30 inches (2 to 76 centimeters) in width, and their chief minerals are quartz, pyrite, sphalerite, galena, and a little chalcopyrite and stromeyerite. The pyrite commonly carries both gold and silver. Most of the veins are so thin that the entire width of sulphide in them is less than 12 inches (30 centimeters). Commonly a thick vein splits into two or more branch veins, which may reunite. The decomposed wall rock contains little disseminated ore, and there has been only slight replacement in the country rock. Veins in the pre-Cambrian rocks may pass upward into the overlying quartzite and there inclose workable ore bodies, but very few continue into the Devonian or Mississippian limestones. The veins in the quartzite in places show distinct crustification. Many of them were rich in gold. Generally pyrite, the most abundant sulphide, is an early mineral; sphalerite, galena, and stromeyerite were deposited later. Ores of this type were the first deposits worked but are now of negligible importance.

Nearly all the ore found in limestone and the greater part of that found in quartzite are of the replacement type. The chief minerals of the replacement ore bodies are pyrite, sphalerite, siderite, quartz, and minor amounts of chalcopyrite, galena, and stromeyerite. The replacement ore shoots generally follow

northeastward-striking faults and pitch approximately with the dip of the beds.

Near the center or lower end of some of the large replacement ore bodies in the Mississippian limestone funnel-like masses of sulphide extend downward through the Devonian limestone into the upper part of the underlying Devonian Parting quartzite. The axes of the elliptical horizontal section of the upper part of these chimneylike masses may be as much as 95 by 220 feet (29 by 69 meters). (See fig. 16). Like most other replacement deposits, they are irregular in outline, both in plan and in cross section, but their width and thickness are generally less than one-quarter the length of the shoot. The length down the dip of the beds ranges from a few yards to approximately 3,100 feet (945 meters). Commonly the larger ore shoots are elliptical in cross section and are from 50 to 100 feet (15 to 30 meters) thick and 75 to 150 feet (23 to 46 meters) wide. Blanket veins, parallel to the bedding of the inclosing rocks, are common in both the Leadville limestone and the Parting quartzite member of the Chaffee formation (Upper Devonian). The largest blanket vein in the Leadville formation is 40 to 50 feet (12 to 15 meters) thick and 75 to 150 feet (23 to 46 meters) wide. The blanket veins in the underlying quartzites are from 2½ to 16 feet (0.75 to 4.9 meters) thick and are generally less than 15 feet (4.6 meters) wide, though locally they may spread to 100 feet (30 meters).

Siderite carrying some magnesium and manganese is very common under and at the sides of the ore bodies but is not plentiful above the ore. Below the siderite are large masses of coarsely crystalline dolomite, and smaller masses are sometimes found overlying the ore. Both the dolomite and the siderite replace the wall rock and fault gouges. Near lead-free zinc ores there is little siderite, but as the lead content increases the amount of siderite surrounding the ore body also increases. Much of the ore consists of moderately coarse grained, porous masses of pyrite and sphalerite, but fine-grained, compact ore is common. Much of the finer-grained mixed zinc-iron ore preserves the laminations, minute fractures, faults, and folds of the country rock which it has replaced. In most places the contact of the ore and the country rock is sharp, but in a few places it is gradational. Well-formed pyrite crystals are common in the wall rock near the ore bodies.

The replacement deposits are found at all horizons in the Leadville and underlying limestones and the older quartzites and shales, but no ore has been found in the younger "Weber shales" or "Weber grits" near Gilman and Red Cliff. Certain beds of quartzite, because of their higher porosity and

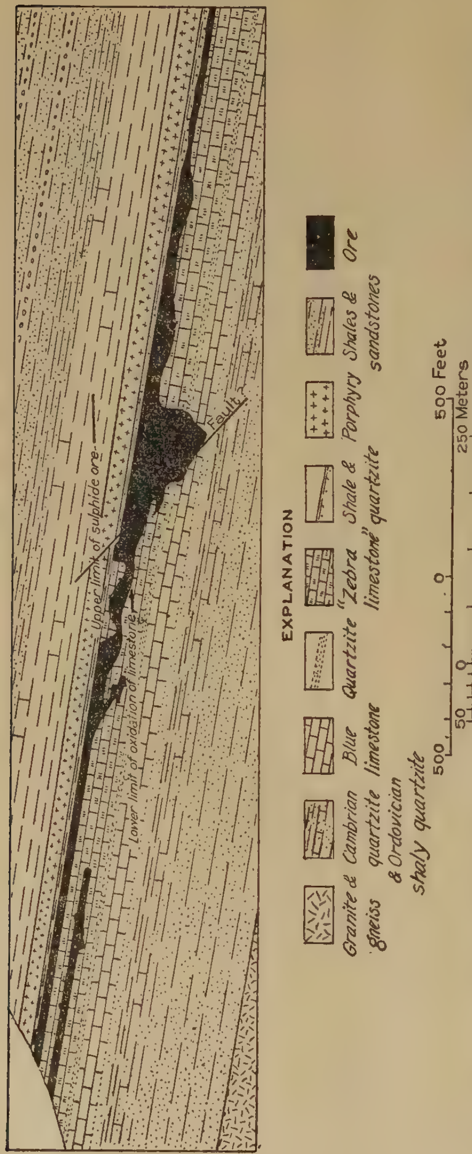


FIGURE 16.—Cross section of Eagle No. 2 ore body at Gilman. After Crawford (8, pl. 3), with slight modifications

higher lime content, were more easily replaced than others. In such beds the ore has much greater horizontal extent than in the compact pure quartzite. The replacement deposits in these lower beds are distinctly related to crosscutting fissures and fissure veins, and many of them may be regarded as widenings of such veins through replacement of favorable beds. Blanket veins in the quartzite follow easily replaceable layers. The lower blanket vein zone is about 160 feet (49 meters) above the bottom of the quartzite, and the second zone about 28 feet (9 meters) above that.

The bulk of the production from this district has come from the large ore bodies found in the upper part of the Leadville limestone. One of the largest ore shoots extended from the bottom of the Chaffee formation to the top of the Leadville limestone, but most of the replacement deposits have been found in the Leadville limestone. The localization of the replacement ore bodies is due to a combination of favorable features of texture, composition, and structure. The Leadville limestone is more granular than the underlying Devonian limestone (Chaffee formation) and contains less silica. The presence of an impervious capping of porphyry or shale at the top of the Mississippian limestone served to guide the ascending mineralizing solutions along the top of this bed.

In some of the pyritic sphalerite replacement ores the two minerals are segregated from each other. A central core of pyrite may be set off sharply from the surrounding shell of sphalerite; or the pyrite may occur along one side of the replacement body and the sphalerite on the other side. In many ore bodies sphalerite and pyrite occur together throughout the ore shoot, which also contains some galena and chalcopyrite. Caves a few inches or several feet wide are found at the border of many ore bodies. They commonly contain pockets of dolomitic sand, composed chiefly of rounded and angular grains of dolomite.

The oxidized ores of the Gilman district were largely mined out before 1900. Most of the oxidized ore was lead carbonate, carrying silver and gold, but there is very little lead in the primary sulphide ores now found in the Leadville limestone. The oxidized ores in the Cambrian quartzite consist chiefly of limonite that carries a little gold and silver, but some lead carbonate is also present.

Because of the more general fracturing of the rocks near the present outcrop, the oxidized ores near the surface generally extend farther from the principal mineralized faults than the deeper sulphide ore bodies. The oxidized ores seldom persist down the dip of the quartzite more than 600 or 700 feet (183 to 213 meters) from the outcrop. Flecks and nuggets of native

gold occur in the oxidized zone of the quartzite deposits, and manganese oxide is common along some of the larger faults.

The tenor of the ore is extremely variable. In general, the gold and silver are related to pyrite and chalcopyrite and not to the galena or sphalerite. Much of the pyritic gold-silver ore carries less than one-fourth ounce of gold and from 10 to 50 ounces of silver to the ton (7 grams of gold and 280 to 1,400 grams of silver to the metric ton). The average tenor of the zinc sulphide replacement bodies in the upper part of the Leadville limestone is approximately 12 per cent of zinc, 1.5 per cent of lead, and 20 to 40 per cent of iron, with almost no gold or silver.

Evidence of a small amount of sulphide enrichment has been noted at some places in the Gilman district, but in general it is unimportant.

The total production of the district in terms of recovered metals through 1930 has been $3,250,000 in gold, 10,500,000 ounces (312,590,000 grams) of silver, 17,000,000 pounds (7,711-050 kilograms) of copper, 110,360,000 pounds (50,058,194 kilograms) of lead, and 247,410,000 pounds (112,222,823 kilograms) of zinc.

ROAD LOG—CONTINUED

Not far beyond Gilman the road cuts through the upper part of the Leadville limestone into the Pennsylvanian shales, then descends in the section until Red Cliff is reached. The quartzite marking the base of the Leadville limestone is reached at 7.5 miles (12.1 kilometers). At 8.25 miles (13.3 kilometers) the road passes through the grits and quartzites of the lower part of the Devonian, and at 8.5 miles (13.7 kilometers) it enters the upper shaly member of the Cambrian quartzite. The contact between the Cambrian quartzite and the pre-Cambrian rocks is exposed at a sharp curve at 9.2 miles (14.8 kilometers). At 9.8 miles (15.8 kilometers) the road reaches Red Cliff.

From Red Cliff to Leadville the road is largely in pre-Cambrian rocks or the glacial or alluvial materials that rest upon the older rocks. The Paleozoic sediments above the pre-Cambrian rocks border the road at varying distances to the left (east), and at several places the road traverses these formations for short stretches.

At 12 miles (19.3 kilometers) a good view is obtained westward up the long glaciated valley of Homestake Creek, and soon thereafter the traveler sees to his left the morainic débris of the south lateral moraine of the Pleistocene Homestake glacier; this ponded the waters in the valley to the south, so that deltaic sediments (seen in the road cut to the left) were laid down.

At Pando (13.8 miles, or 22.2 kilometers) another marked terminal moraine crosses the road. North from Pando may be seen a broad valley, which is followed by the highway and is tributary to Homestake Creek. The Eagle River once flowed in this valley but was ponded by the moraine and diverted through the narrow gorge to the east, which is now followed by the railroad.

At 14.8 miles (23.8 kilometers) the topography opens southward suddenly, disclosing a wide valley (Eagle Park). This is of glacial origin, but its lower (northern) end has been dammed by the moraine north of Pando, and subsequent alluviation has filled its bottom to a plain sloping gently northward. Some of the low alluvial benches are well seen at 15.6 miles (25.1 kilometers). The headward extension of the glacial valley now represented by Eagle Park is visible to the south at 19 miles (30.6 kilometers).

At 14.6 miles (23.5 kilometers) the Paleozoic section resting on pre-Cambrian schists may be seen on the left. The Leadville limestone and the Chaffee formation, which caps the Cambrian quartzite at this locality, are almost entirely converted into fine-grained chalcedonic quartz or "jasperoid."

At 21.8 miles (35.1 kilometers) there is a good view, down the Eagle River to the right (north), of the unconformity between the Cambrian quartzite and the pre-Cambrian quartzite, which caps a long, smooth slope on the west side of the river.

At 25.8 miles (41.5 kilometers) is Tennessee Pass, on the Continental Divide, separating the Eagle River drainage, which runs into the Colorado River and thus into the Gulf of California, from the Arkansas River drainage, which flows into the Mississippi River and thus into the Gulf of Mexico. Tennessee Pass is 10,424 feet (3,177 meters) above sea level. The bedrock is pre-Cambrian schist.

The road leaves the pass and descends Tennessee Creek to a point near the junction of the creek with the Arkansas River, where it swings to the left (east) across the Arkansas Valley and over a lateral moraine into Leadville, entering the city at 35.4 miles (57 kilometers).

LEADVILLE MINING DISTRICT

By G. F. Loughlin and C. H. Behre, Jr.

LOCATION AND SURFACE FEATURES

The Leadville mining district, one of the most productive in Colorado, lies on the west slope of the Mosquito Range. The city of Leadville is at an altitude of 10,150 feet (3,093 meters), the mines are at altitudes as great as 12,000 feet (3,657 meters),

and the summits of the highest peaks of the range exceed 14,000 feet (4,267 meters). The western slope of the range, especially in the mining district, consists of a number of spurs, each of which is cut into a steplike series of hills separated by faults of large displacement and rounded by erosion in late Tertiary and Quaternary time.

PRODUCTION

The greatest production of the district has come from Carbonate, Fryer, Iron, Rock, and Breece Hills and from the lower-lying part of the district, which, because it is within the city, is commonly referred to as the Downtown district. These features, as well as the location of some of the more productive mines, are shown in Figure 17.

According to Henderson (17),[10] Leadville ranked in 1922 sixth among mining districts in the United States in total value of nonferrous metals produced. Up to 1930, inclusive, it had yielded[11] about $446,167,000 worth of ores, of which 12 per cent was gold, 43 per cent silver, 21 per cent lead, 21 per cent zinc, and 3 per cent copper. At different times it has also furnished considerable pyrite for sulphuric acid and smaller quantities of bismuth, and even to-day it produces some manganese ore. For a time, long ago, it supplied iron of unrecorded value from the magnetite and hematite deposits of Breece Hill.

GLACIATION AND TERRACES

The Leadville district has been affected by at least two stages of glaciation. The crest of the range is flanked by cirques, and the larger U-shaped gulches are bordered by lateral moraines that coalesce into terminal moraines. Only moraines of the last glacial stage are well preserved in the vicinity of Leadville, notably along Evans and Iowa Gulches. Those of the earlier stage were chiefly removed by erosion during the interglacial stage or the last glacial stage.

The western base of the range is largely bordered by extensive outwash aprons, formed during the earlier glacial stage, that slope gradually westward to the valley of the Arkansas River. Similar but lower-lying terraces bordering the Arkansas River below Leadville represent outwash of the later glacial stage.

The older or high-terrace gravel deposits overlie an obscure formation of fine sand, clay, and marl, called "lake beds."

---

[10] Numbers in parentheses refer to bibliography on p. 143.

[11] Personal communication from Chas. W. Henderson, U. S. Bureau of Mines.

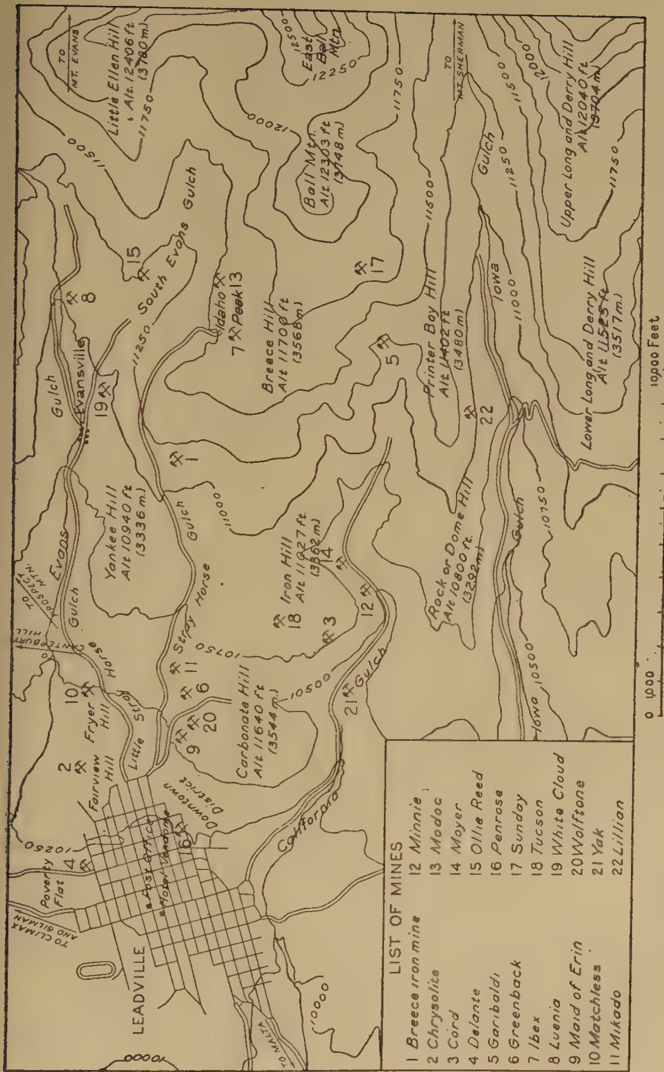


FIGURE 17.—Map showing positions of the hills and gulches and some of the principal mines of the Leadville mining district

These beds are not exposed at the surface but have been cut by several shafts in the immediate vicinity of Leadville. They may have been formed in a lake, or they may represent fine alluvium deposited in late Pliocene or early Pleistocene time. They have been elevated to their present position above the valley of the Arkansas River by a continuation of intermittent faulting that was most pronounced in Pliocene time.

The glacial deposits effectively conceal bedrock over considerable areas, especially in the western part of the district, and maps of the bedrock geology have therefore been platted to a considerable extent by the upward projection of contacts from mine workings.

GEOLOGY OF THE BEDROCK

Pre-Cambrian and sedimentary rocks.—The bedrocks include formations of pre-Cambrian, Cambrian, Ordovician, Devonian, Mississippian, and Pennsylvanian age.

Stratigraphic section of the Leadville district, Colorado

Age	U. S. Geol. Survey Prof. Paper 148	Latest revision	Average thickness	
			Feet	Meters
Pennsylvanian.	Weber (?) formation:	Weber (?) formation:		
	Grits	Grits	940	287
	Shales	Shales	0–300	0–91
Mississippian.	Leadville or "Blue" limestone	Leadville limestone restricted	120	36.6
Devonian.		Chaffee formation:		
		Dolomite	80	24.4
	Yule limestone:			
	"Parting" quartzite member	Parting quartzite member	27	8.2
Ordovician.	"White" limestone member	Manitou or "White" limestone	95	28.9
Cambrian.	Sawatch quartzite:	Sawatch quartzite:		
	"Transition shales"	Calcareous shale	45	13.7
	Quartzite	Quartzite	90	27.4
Pe-Cambrian	Granite, gneiss, and schist.			

Very little of the pre-Cambrian complex of granite, gneiss, and schist is seen at the surface in the Leadville district, although it is cut by mine workings in many places. By far the greater part of the pre-Cambrian rock shown in and near the mines is medium-grained pink granite, generally weathering grayish, with prominent trachitoid feldspar crystals. All the granite is probably to be correlated with the Silver Plume granite of the Front Range of Colorado.

The Sawatch quartzite, of Upper Cambrian age, includes a thick lower quartzite and a thinner upper shaly member. It rests upon a smooth pre-Cambrian surface. The quartzite contains a few beds that have matrices of sericite or calcite, and these beds are impregnated at several places with sulphides, principally pyrite; but the only ore mined in much quantity from the quartzite in the Leadville district has occurred in veins that cut across the bedding.

The upper member, called "transition shales" by the miners because it suggested a gradation from the quartzite below into the "White" limestone above, consists mainly of alternating thin layers of shale and light-gray to white magnesian limestone. Where mineralization has been intense the limestone layers have been replaced by low-grade ore.

The Manitou or "White" limestone differs from the "transition shales" mainly in containing beds of light-gray to white dolomitic limestone separated by thin partings of shale. Thin layers and streaks of white chert are conspicuous at certain horizons. Owing to the abundance of its shale partings, it is less subject to persistent fissuring than the Devonian and Mississippian limestones, and it has accordingly been replaced by large ore bodies only in the vicinity of the main channels along which ore-forming solutions were introduced. Such replacement deposits are conspicuous under impervious covers, notably sills of porphyry and the shaly beds at the base of the overlying formation.

The Parting quartzite, or basal member of the Chaffee formation, is prevailingly a coarse, uneven-grained rock with local shaly beds, especially at the base. It was deposited on an erosion surface of the "White" limestone. It has been replaced by ore at a few places along channels of intense ore deposition.

The overlying dolomite member of the Chaffee formation, which was formerly regarded as the lower part of the Leadville limestone, is readily distinguished by its gray color on weathered surfaces, which contrasts strongly with the dark outcrops of the overlying Leadville limestone as now restricted, and by its more uniformly crystalline and "sugary" texture. Its beds are mostly 2 to 4 feet (0.6 to 1.4 meters) thick. Its susceptibility to

replacement by ore is apparently slightly less than that of the Leadville limestone.

The Leadville limestone as now defined is the upper part of the "Blue limestone" of earlier reports. It has a basal member, 8 feet (2.4 meters) in maximum thickness, consisting of sandstone and limestone breccia of sedimentary origin. The sandstone may occur in one thick bed or in several thinner beds. Locally it is absent and the base of the formation is marked only by the limestone breccia. The dark-blue rock above this basal member is a nearly pure dolomite. The uppermost 30 feet (9 meters) of the formation is coarse grained and contains prominent nodules, streaks, and lenses of black chert and locally layers of shale. The Leadville limestone has been far more extensively replaced by ore than any of the other formations, not only along the channels of most intense mineralization but also and especially along persistent sheeted zones that extend across those channels. One most effective factor in the control of this extensive deposition is the thick, impervious cover of porphyry or of "Weber shales" at the top of the "Blue" limestone. Partly on account of its continuity, this cover has been a far more effective barrier to ascending solutions than any of the shaly beds or porphyry sills at lower stratigraphic horizons.

The Weber (?) formation, though extensive in the eastern part of the district and elsewhere in the Mosquito Range, is almost wholly absent in the western part. Its lower member is black shale, with some impure coal beds and a few lenses of limestone. Its upper member consists of gray medium to coarse grained micaceous, feldspathic sandstone and white micaceous quartzite. Ore in the "Weber grits," as in other siliceous rocks of the district, is mainly confined to veins that cut across the bedding, but exceptionally ore spreads for several feet from the vein along a replaced bed.

Igneous rocks.—The sedimentary rocks were invaded in late Cretaceous or early Tertiary time by prophyry of two distinct kinds.

The earlier, locally called White porphyry, is equivalent to a muscovite granite in composition. It forms an immense intrusive sheet between the "Weber shales" and "Blue" limestone and several thinner and less extensive sheets at lower horizons.

The later or Gray porphyry includes four recognized varieties which differ mainly in texture and in the presence or absence of certain phenocrysts. All are essentially quartz monzonites. The most striking variety shows phenocrysts of orthoclase as much as 2 inches (5 centimeters) in length and smaller, very regular bipyramids of quartz. These varieties were intruded

at different times, but so far as their relations to the occurrence of ore are concerned they may be regarded as one group. The Gray porphyry forms several intrusive sheets, some of which are very irregular. They are best seen in Evans Amphitheater, northeast of Leadville, where the thickest is 650 feet (198 meters) thick and approaches a laccolith in form. The most extensive of these sheets overlies a White porphyry sill on top of the Leadville limestone. The others are mostly in the Leadville, Chaffee, and Manitou limestones and in the upper member of the Sawatch formation. They decrease in number westward, and only one, in the Leadville limestone, extends into the Downtown area, beneath the city of Leadville. They increase in thickness and complexity in the southern parts of Iron Hill and Breece Hill and are accompanied by dikelike offshoots of considerable size. At Fryer Hill and Printer Boy Hill dikes of Gray porphyry cut the Leadville limestone and White porphyry.

At a much later time, subsequent to ore deposition and to at least a part of the postmineral faulting described below, eruptions of rhyolite agglomerate took place. The rocks thus formed are not well exposed at the surface near Leadville, but somewhat similar rock, probably of the same age, may be seen about 10 miles (16 kilometers) northeast of Leadville, on the highway to the Climax district. Four funnel-shaped pipes of agglomerate have been partly outlined by mine workings, and in places they cut off ore bodies. Several small dikes of rhyolite, similar in appearance to the White porphyry, also appear to belong to the same period of igneous activity.

Structure.—The intrusion of the irregular sheets and dikes of Gray porphyry greatly disturbed the sedimentary rocks, particularly the Leadville limestone. Blocks of limestone were thrust aside here and there, with abundant local fracturing. This was the earliest of four periods of faulting.

The three subsequent periods included reverse faulting, minor premineral normal faulting, and major postmineral faulting. Some faults were subjected to movement during more than one period and have been designated composite faults.

Subsequent to the intrusion of the Gray porphyry sills, the region was subjected to folding and reverse faulting. The principal folds formed in and around Leadville were anticlines of north-northwesterly trend, with gently sloping eastern limbs and steep or even overturned western limbs. The western limbs were broken by reverse faults of moderate to steep northeastward dip. The largest of these reverse fault movements are on the portion of the Weston fault that lies south of Iowa Gulch; on the Mike fault south of Printer Boy Hill; on the

Mosquito fault to the north, in the Tenmile district; and on the London fault on the east side of the Mosquito Range. Two of these faults belong to the composite group. The portion of the Mike fault that lies north of Printer Boy Hill was subjected to postmineral movement in an opposite direction along the west side of a local depressed block, and its present attitude is normal. The same may be true of the portion of the Weston fault that lies north of Iowa Gulch, and of the Mosquito fault. Within the Leadville district several smaller reverse faults have also been recognized, notably the Colorado Prince fault, along the northeast edge of Breece Hill; the Bowden fault, in the Yak tunnel and the Ibex mine, in Breece Hill; the Tucson-Maid fault, exposed in mines of Iron and Carbonate Hills; the Dyer fault, southeast of East Ball Mountain; and a few more between the Dyer fault and the Continental Chief mine. After the formation of the reverse faults, fissures and small normal faults were formed at right angles to them, and some of these offset the earlier faults for short distances.

In adjacent parts of central Colorado the period of folding and reverse faulting was followed by the intrusion of stocks and batholiths of monzonitic rock. No comparable intrusions have been definitely recognized in the Leadville district, but the distribution of ore bodies, particularly those containing magnetite, suggests that the altered stock which makes up most of Breece Hill may represent an intrusion of this type. At the same time as this late stocklike intrusion, or shortly afterward, more minor normal faults were formed, many of them with radial arrangement around the stock.

The whole sequence of events, from the intrusion of the White porphyry to and including the deposition of ore, took place in late Cretaceous or early Tertiary time. In late Tertiary time normal faulting ensued on a large scale and divided the district into several fault blocks. In general the trends of these faults are northerly and the dips westerly. Some of the movements of this period consisted of renewed faulting on lines already determined by the earlier thrusts, notably along the Mosquito, Weston, and Mike faults.

ORE DEPOSITS

Hypogene ore deposits.—The ore deposits extend far beyond the area shown in Figure 17, but the largest are in the western part of this area. Their distribution and size are due mainly to structural conditions, and their form and in part their primary mineralogy to the character of the country rock. The hypogene deposits are conveniently classified into three main groups, which, named in order of increasing commercial im-

portance, are (1) the silicate-oxide replacement deposits, formed at relatively high temperatures in limestone; (2) the mixed sulphide veins, formed at moderate temperatures, mainly in siliceous rocks; and (3) the mixed sulphide replacement bodies, formed at moderate temperatures, chiefly in limestones. In addition to these three classes of deposits found in the immediate environs of Leadville, there are more distant replacement deposits in the outlying country which were formed at relatively low temperatures and differ from those within the district mainly in the ratio of the different sulphides and in the character of the gangue minerals.

1. The silicate-oxide deposits are of little commercial importance. Magnetite-hematite ore was shipped from the Breece iron mine for smelter flux in the early days of the district, but with this exception only the ore cut by pyritic gold veins and thus enriched to a workable tenor has been mined. The original gangue minerals, evidently pyroxene and perhaps olivine, have been thoroughly serpentinized since deposition. Ore of this class is restricted to limestone in the immediate vicinity of the obscure intrusive stock at Breece Hill.

2. The veins of mixed sulphides occur mainly in siliceous rocks, which predominate in the eastern part of the district owing to the abundance and complexity of the sill-like intrusions in and near the Breece Hill stock. Veins within the stock have been productive only in their enriched portions near the surface. The largest outside of the stock have been productive to a depth of 1,300 feet (396 meters), the level of the Yak tunnel, but even their deepest workings show some evidence of sulphide enrichment.

The Garbutt vein fills a fault that cuts grits and shales of the Weber (?) formation on the upper levels and has a wall of Cambrian quartzite along the lowest levels, but any limestones that would be expected on intermediate levels have been crowded out by a thick, irregular mass of porphyry. The largest vein of the Ibex mine also fills a fault, but limestone along it is in its normal stratigraphic position and has been extensively replaced by ore. Small veins also expand into replacement bodies where they cross masses of "White" limestone that are separated by porphyry sills or are capped by Parting quartzite. (See fig. 18.)

These replacement bodies have been profitably mined, mainly for gold, but the parts of the veins that cut the porphyry sills or quartzite are generally too narrow to be mined and serve only as guides to near-by masses of replaced limestone. Another large vein, the Luema, fills a fault that crosses both limestones, but its walls are so thoroughly protected by gouge that the adjacent limestones have escaped replacement.

Where the veins cut siliceous rocks they consist mainly of pyrite with a little interstitial chalcopyrite in a gangue of quartz. Where they expand into replacement deposits pyrite and quartz persist for a short distance laterally but grade into a mixture of zinc blende and galena incased in dense quartz or jasperoid. The veins and the pyritic parts of the replacement deposits have been valuable mainly for gold, some of which is primary but much of which has resulted from enrichment in the secondary sulphide zone. The gold is accompanied by some silver and in several veins by copper. Lead shoots have also been productive.

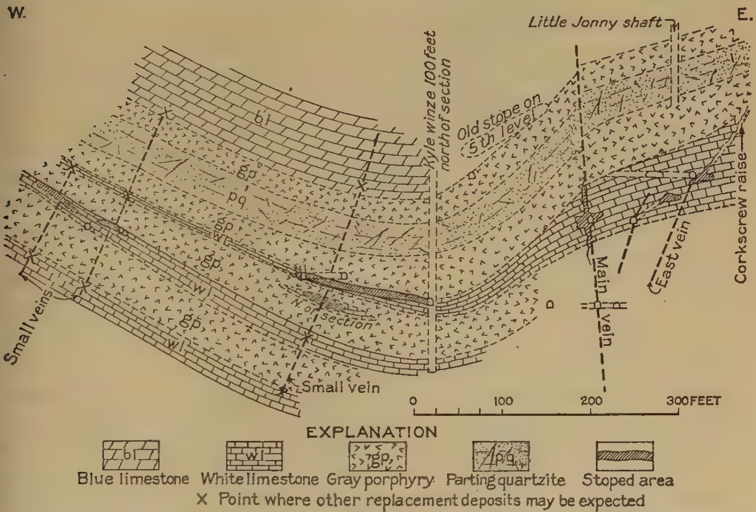


FIGURE 18.—East-west section 20 feet north of Little Jonny shaft, showing relation of veins to blanket ore bodies in the Golden Eagle workings, Breece Hill

Zinc is commonly more abundant than lead. The outer parts of the replacement bodies, which consist mainly of zinc blende and galena, also contain some silver, but owing to their small size and the high cost of mining them, they have not been very important sources of ore. In most respects except size these outer parts of the replacement bodies are essentially identical with the large replacement deposits that are best developed in the western part of the district.

3. In the western part of the district veins are relatively scarce and sulphide replacement deposits in limestone are large and so numerous that the bulk of the district's production has come from them. These replacement bodies or "blankets" lie along

fractures or sheeted zones beneath impervious covers. There are several contacts that are favorable for the occurrence of ore. The most favorable, known as the "first contact," is that at the top of the Leadville limestone. Other contacts are numbered consecutively downward. In some places, notably Dome Hill, only one or two contacts have been productive; but in Carbonate Hill and Iron Hill as many as eleven contacts have been developed. The largest replacement bodies, at the top of the Leadville limestone, exceed 2,000 feet (610 meters) in length, 800 feet (244 meters) in width, and 200 feet (61 meters) in thickness.

The relations between these large replacement bodies and the few veins that have been found associated with them are essentially identical with those in the eastern part of the district. To illustrate, the Cord vein, in the Iron Hill area (fig. 19), has been mined from the "Blue" or Leadville limestone down to the pre-Cambrian granite. Where it passes through the limestones it expands into replacement deposits. Ore mined from the vein between siliceous walls was pyritic gold ore, whereas that mined from the replacement bodies in limestone was silver-bearing zinc and zinc-lead ore.

The western part of the district illustrates the trunk channels along which solutions traveled and the relations of these channels to the pre-mineral reverse faults described on page 84. The Tucson-Maid fault (see pl. 9), which trends northwest and dips east, is one of the largest of these reverse faults. It passes through Iron and Carbonate Hills and is offset by a strong zone of postmineral faults midway between these two hills. Its northwestward continuation in the Downtown area is offset by another zone of postmineral faults along the west slope of Carbonate Hill. The dip of the fault plane is 45°–50° in the lowest workings but decreases upward to coincide with that of the beds at or near the base of the Leadville or "Blue" limestone. Because of this conformity to the bedding the fault escaped discovery until about 1908.

Although the main fault plane was too "tight" and full of gouge to permit the free passage of ore-forming solutions, the adjacent auxiliary fissures afforded channels for such circulation. Some of these solutions, stopped in their upward progress by the gouge-filled fault, penetrated into the footwall and there replaced "White" limestone. Others rose from the fault or auxiliary fissures into the hanging wall and, gaining access to a persistent sheeted zone of east-northeast trend, formed large replacements in the "Blue" limestone. (See pl. 9.)

The principal primary gangue mineral in and around the ore bodies nearest the Tucson-Maid fault is manganosiderite,

Figure 19.—Cross sections of ore bodies along the Cord vein, Iron Hill. gp, Gray porphyry; bl, Leadville ("Blue") limestone; pq, Parting quartzite; wl, "White" limestone; €q, Cambrian sediments. After Emmons, Irving, and Loughlin (12, fig. 23)

which has also been found closely associated with magnetite in the outer parts of the silicate-oxide zone. This mineral preceded the sulphides and quartz, both of which have replaced it to a considerable degree. The replacement deposits farther from the Tucson-Maid fault are incased in dense quartz or jasperoid. A small amount of barite is present in the outermost parts of these ore bodies.

The most abundant sulphide is pyrite, and this forms some large masses that are accompanied by so little silver and gold as to be of no value. Some pyrite was formerly shipped for the manufacture of sulphuric acid, but there has been no demand for it since the World War.

Nearly pure masses of ferruginous zinc blende are occasionally found, and the same is true of galena, but for the most part these two minerals occur together, associated with pyrite. This mixed sulphide ore commonly contains a few ounces of silver and 0.03 to 0.05 ounce of gold to the ton (0.8 to 1.4 grams to the metric ton), but here and there small shoots have been found that are unusually rich in silver and gold and also contain bismuth. Intergrowths of argentite, bismuthinite, and a little galena have been found in this rich ore.

Supergene ore deposits.—Climatic conditions during late Tertiary time were favorable for oxidation and enrichment of ores to considerable depths, but Pleistocene glaciation scoured off much of the oxidized material in the eastern part of the district. Since Pleistocene time oxidation has been insignificant.

Supergene processes have given rise to several different classes of oxidized ore and a minor though locally considerable amount of enriched sulphide ore. Water seeping downward through the pyritized White porphyry became charged with sulphuric acid and ferric sulphate, which were very effective in attacking the sulphides in the underlying Leadville limestone. Galena was oxidized through anglesite to cerusite without appreciable migration. The cerusite was accompanied by considerable horn silver, especially close to the surface. Zinc blende was completely dissolved and the zinc redeposited as the carbonate (smithsonite) and the silicate (calamine), which replaced limestone, dolomite, or manganosiderite at favorable places beneath the original sulphide ore body (23). Where manganosiderite was the only abundant gangue mineral around the ore body and graded outward into limestone or dolomite, large bodies of high-grade oxidized zinc ore were formed; where dense silica was the predominating gangue, or where a sill of Gray porphyry lay a short distance below the original ore body, the zinc solution became scattered in passing through these unreplaceable rocks, and only small bodies of low-grade ore were formed.

Oxidation of large pyrite masses produced correspondingly arge deposits of limonitic iron ore, partly in place and partly y the replacement of adjacent carbonate rock. Oxidation of nanganosiderite produced black manganese-iron ore and locally ome high-grade manganese oxide. Both the iron and the nanganese-iron ore have been mined for furnace flux, and the nanganese-iron ore is still of importance in steel manufacture. The value of these ores as fluxes was increased by their small ontent of silver and lead. Oxidation of the small sulphide hoots containing unusually large quantities of bismuth proluced deposits of bismuth oxide and carbonate that have been ntermittently productive.

Much of the copper was carried below the oxidized zone and vas redeposited as coatings of chalcocite on chalcopyrite and yrite. This chalcocite appreciably increased the copper content of the ore but was probably more valuable as a precipitant f gold and silver from descending solutions. Zinc blende was lso effective in precipitating the gold. Some very rich bunches f ore have been mined that contained gold coatings on zinc lende, and some of the richest shoots in the present oxidized one evidently represent ore that had first been enriched in this vay. This rich oxidized ore accounts for the coarse gold found n the placers along California Gulch.

Rich silver ore has been mined just below the oxidized zone n some of the large replacement bodies. The silver is in the orm of leaf and wire silver and of argentite, which were deposited n the original sulphides by descending solutions.

ROAD LOG—CONTINUED

The road leads over morainal deposits from Leadville to the ridge across the Arkansas River. At the river a good view may e had of the Upper Cambrian Sawatch quartzite, the Ordovician "White" limestone, the Devonian Chaffee formation, and he Mississippian Leadville limestone, cropping out in the side f the valley directly ahead. These eastward-dipping beds soon ass below the level of the valley. Porphyry sills in the Pennylvanian grits and shales are well exposed at several places.

At 6.4 miles (10 kilometers) from Leadville the road passes n the right-hand side of a porphyry sill which forms a knob early 300 feet (91 meters) high. A prominent recessional noraine is seen at 7.5 miles (12.1 kilometers), crossing the valley. The conspicuous white mass on the right-hand side of the road t 9.6 miles (15.4 kilometers) is much altered monzonite porhyry cutting Pennsylvanian shales and sandstones. The cliffs n the left at 11 miles (17.7 kilometers) consist of rhyolite gglomerate, the latest intrusive rock in the region.

113723—32——7

At 12.6 miles (20.3 kilometers) Fremont Pass (altitude 11,32 feet, 3,450 meters) is reached. The road swings back across th Continental Divide, and a road leading to Climax branches o to the right. There is a good view of the glacial valley of th Arkansas River cut by Wisconsin ice, and an earlier valley ma be traced passing to the left over Fremont Pass. The old valle was cut by early Pleistocene ice and was later beheaded by th Arkansas. (Excursion 2 turns to the right to visit the molyb denite deposits of the Climax Molybdenum Co.)

The molybdenite deposits of Climax are the largest in th world and have supplied over 90 per cent of the world's pro duction for several years. A brief description of the geolog of these ore deposits, condensed from a paper by Butler an Vanderwilt (4), is given below.

THE MOLYBDENUM DEPOSIT AT CLIMAX

By John W. Vanderwilt

LOCATION AND TOPOGRAPHY

The Climax district is in northeastern Lake County, Colorad Climax station is on Fremont Pass, on the Continental Divide and a narrow-gage line of the Colorado & Southern Railroa gives connection daily with Leadville and Denver. The statio is 13 miles (21 kilometers) north of Leadville and is on the auto mobile highway from Leadville to Dillon. The highway i generally closed by snow from December to April, but railroa connections are maintained throughout the year. The molyb denite deposit and old mine workings are in Tenmile Amphithea ter, nearly 1 mile (1.6 kilometers) west of Climax and about 60 feet (183 meters) higher.

Fremont Pass is a broad open divide, and the Tenmile Valle is also open, but the mountains to the east and west have a ver rugged topography. Altitudes in the district range from 11,00 to 13,600 feet (3,350 to 4,145 meters). A very conspicuou topographic feature within the district is Tenmile Amphitheate which lies east of Climax and faces west. This amphitheate is limited on the north by Bartlett Mountain and on the sout by Ceresco Ridge; Clinton and McNamee Peaks rise at its head

CLIMATE

The winters in this district are long and the summers short The winters are characterized by abundant snow, high winds and subzero (Fahrenheit) temperatures. Freezing temperature and snowfalls may occur even in June, July, and August. Gener ally there are daily showers during July and August. Timbe line is at about 11,600 feet (3,536 meters), and the timbe (spruce and fir) is chiefly of a subalpine type.

HISTORY AND PRODUCTION

As late as 1890 the molybdenite at Climax was mistaken for graphite, but it was definitely identified by 1895 or 1900. Little or no effort was made to produce molybdenum until 1914 or 1915.

The Climax Molybdenum Co., the present owner of the deposit, first began active exploration in 1917 and by February, 1918, was producing ore at the rate of 250 tons daily. Production was suspended in April, 1919, because at the end of the war there were large stocks of molybdenum available and demand and price decreased greatly. The company kept its plant in shape, however, and in addition spent much money in metallurgical research and widespread advertising of the value of molybdenum steel. Mining operations were resumed in August, 1925, and planned for a limited yearly output. However, demand exceeded expectations, and production was increased from 150 tons daily in 1925 to 1,200 tons in 1928, which has been continued to the present time. Production by years is shown in Figure 20.

MINING METHODS [12] AND ORE RESERVES

Both the mine and the mill are operated by electric power. The mill is in the town of Climax, at an altitude of about 11,325 feet (3,452 meters). The mine is about a mile to the west, and the White adit is at an altitude of about 11,900 feet (3,627 meters). Mining is done by the "shrinkage stope" and "cave" method. Prior to 1930 the crushed ore was carried by tram from the White adit to the mill. The Phillipson tunnel was completed in 1931 in order to get more economical delivery of ore to the mill. This tunnel is 465 feet (142 meters) lower than the White level, and its portal is only 2,200 feet (671 meters) from the mill. The primary crushing plant takes pieces of rock as much as 30 inches (0.76 meter) across and has a capacity of 300 tons an hour. Since 1931 the ore mined above the White adit has been passed through an inclined shaft from the White level down to the Phillipson tunnel and transported in electrically operated trains of twenty 10-ton cars to the new crushing plant and mills.

Concentration is effected by selective flotation. The molybdenite is exceedingly fine grained, usually only a fraction of a millimeter across, which necessitates grinding to about 100 mesh. By the method employed 85 to 90 per cent is recovered, and molybdenite concentrate with a grade of about 88 per cent or better is produced.

The molybdenite content ranges from 2 per cent down, but large tonnages carrying more than 1 per cent have not

[12] For details see Coulter (6).

been found. In April, 1931, the company estimated that abou
85,000,000 tons of 0.8 per cent molybdenite rock had been de
veloped by diamond drills and mine workings. Under the con
ditions prevailing in 1931, 0.8 per cent molybdenite constitute

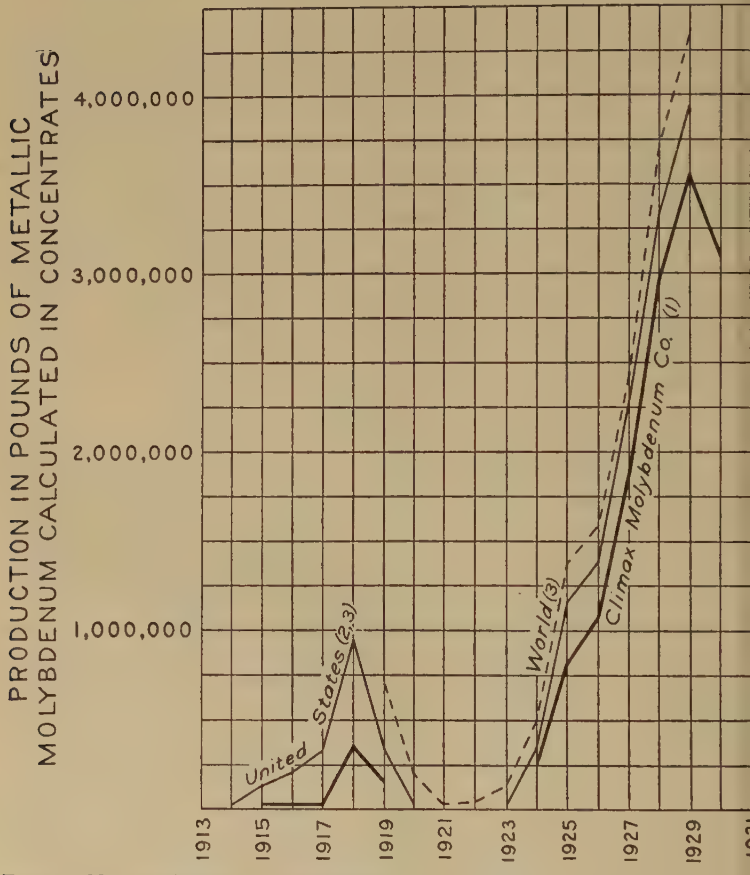


FIGURE 20.—Production of molybdenum in the Climax district, 1914–193
(1) The deposit in 1918 should be credited with a small additional productio
from the Denver claim. (2) Hess, F. L., U. S. Bur. Mines Mineral Resource
1928, pt. 1, p. 110, 1929, and prior volumes. (3) Kissock, Alan, Miner
Industry, 1929, p. 448

ore. This ore reserve represents only partial development o
ground above the Phillipson tunnel level. All indications poin
to continuation of ore with depth, and in one place a vertica
diamond drill was in 0.8 per cent ore for a depth of 480 feet (14

meters) below the Phillipson tunnel level. Because of the large tonnage of ore available above the Phillipson tunnel level, development below this level is not contemplated at present.

GEOMORPHOLOGY AND GLACIATION

The valley of Tenmile Creek northwest of Climax is broad and open and is cut off abruptly from the valley of the East Fork of the Arkansas River at Fremont Pass by a steep drop of 300 feet (92 meters). The upper part of the East Fork Valley above Fremont Pass has the same trend as the Tenmile Valley—a fact which suggests that the East Fork was once the head of Tenmile Creek. The capture of the East Fork by the Arkansas River probably took place in preglacial time.

There were two or more stages of glaciation. High on the slopes of Chalk Mountain, west and north of Fremont Pass, there is a lateral moraine which probably represents the earliest stage. The more recent moraines, well preserved and only slightly weathered occur on Fremont Pass and in the Tenmile Valley about 2 miles (3.2 kilometers) northwest of Climax. During high stages of glaciation the ice of an Arkansas River glacier spilled over Fremont Pass.

Prominent terraces of talus fringe Tenmile Amphitheater, especially on the north and south slopes. These terraces probably represent débris that accumulated on the ice from the steep sides of the cirque during the final stage of glaciation, when the bottom of the amphitheater was filled with stagnant ice.

GEOLOGY

Pre-Cambrian crystalline rocks, Paleozoic sediments, and Tertiary intrusive rocks occur in the Climax area. Their distribution is shown on Plate 10.

Pre-Cambrian rocks.—The oldest rock in the district is biotite schist, which contains quartz and some plagioclase. The schist is uniform in appearance and mineral composition throughout the area. It is similar to and is tentatively correlated with the Idaho Springs formation at Idaho Springs, Colorado.

Gray to pinkish-gray, medium to coarse-grained, massive granite intrudes the schist, and numerous schist inclusions occur in the granite throughout the area. Feldspar, quartz, biotite, and muscovite can be recognized megascopically in the granite. The feldspars are chiefly microcline with some orthoclase and oligoclase. Small amounts of magnetite, titanite, and garnet are also present.

The granite is similar in petrography and manner of occurrence to the Silver Plume granite of the Georgetown area, Colorado.

Paleozoic sedimentary rocks.—Beds presumably of Pennsylvanian age and corresponding to the "Weber grits," or possibly to the lower part of the overlying Maroon formation, occupy the western part of the area, but as neither their base nor their top is exposed the exact horizon represented is not certain.

The sedimentary rocks are bounded and separated from the crystalline rocks on the east by the Mosquito fault. The only sedimentary rocks east of this fault are two small remnants of Cambrian (Sawatch) quartzite. The upper portion of the Cambrian quartzite, the Ordovician ("White") limestone, the Devonian (Chaffee formation), and the Mississippian (Leadville) limestone, all ore-bearing at Leadville, do not crop out in this area.

Tertiary intrusive rocks.—Dikes and sills cut the sedimentary and older crystalline rocks. They consist of quartz monzonite or granite and are characterized by a light-gray color and conspicuous quartz phenocrysts. In places large orthoclase phenocrysts are abundant. Biotite is generally present, and in thin section the porphyry shows abundant oligoclase to andesine plagioclase with much orthoclase and quartz in the groundmass. These intrusives are correlated with the Lincoln porphyry, which is common throughout the Mosquito Range from Leadville to Breckenridge.

The sills in the sedimentary rocks weather very easily to gravel, but the dikes in the granite break into massive slabs and fragments. This difference is also marked underground; in the Phillipson tunnel the porphyry sills in the sedimentary rocks require timbering, whereas the porphyry dikes in the granite stand well unsupported.

Structure.—The sedimentary formations lie in a syncline with its axis plunging north. This fold is the continuation of a large syncline under Jaques Mountain (11). The east limb of the syncline is terminated by the Mosquito fault, a major structural feature traceable south to Leadville and also north into the Tenmile area. The fault is not marked by topographic features and is therefore inconspicuous. The strike is N. 9° E., and the dip 71° W. Movement on the fault has raised the base of the Cambrian to a level with Pennsylvanian beds. The actual displacement can not be calculated, because no reliable stratigraphic horizon in the Pennsylvanian formation has been determined. The fault is later than the Tertiary quartz monzonite sills in the sediments, but its age relative to the mineralization is not definitely known. Some movement along the fault has occurred later than the mineralization, as indicated by the presence of mineralized granite rubble in the fault gouge. Evidence has not been found that might prove or disprove that displacement occurred before mineralization.

Fissures that have no apparent relation to the Mosquito fault are conspicuous both on the surface and underground in the granite and schist throughout the area. These fissures are mineralized, but slickensides indicate that movement has occurred, at least along some of them, after mineralization. The postmineral movements were small, as the Tertiary dikes are not perceptibly offset.

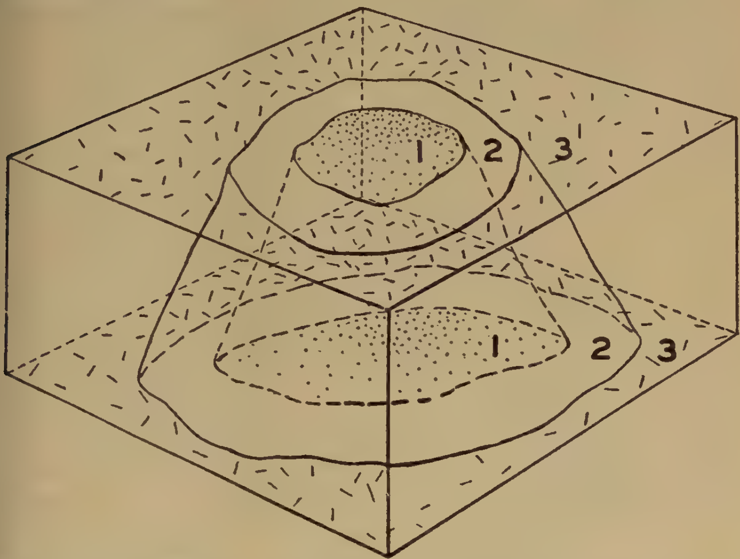


FIGURE 21.—Stereogram showing the general relations of the different zones at Climax. 1, Highly silicified core; 2, ore zone with chiefly moderately silicified granite; 3, slightly altered granite grading into unaltered granite

THE MOLYBDENUM DEPOSIT

Areal extent and form.—A circular area about 1 mile (1.6 kilometers) in diameter of yellow to brown iron-stained rocks is a very striking feature in Tenmile Amphitheater. The economic portion of the molybdenite deposit is also circular, a little over 1,000 feet (305 meters) in diameter, and is in the central portion of the iron-stained or mineralized area. The high color of the rock is superficial and is due to the oxidation of pyrite, but the color effect is the same whether much or little pyrite was originally present. The rocks involved are chiefly pre-Cambrian granite with schist inclusions and Tertiary dikes.

The deposit as revealed by mine development (fig. 21) is a circular stock which enlarges downward from the surface to the lowest level (Phillipson tunnel) of the mine. The relation of the

Phillipson tunnel to the deposit is shown by the block diagram in Figure 22, which also shows the principal geologic feature encountered in the tunnel.

Type of mineralization.—The outstanding change of the gran ite is silicification, which has been very feeble in the outer por tions of the iron-stained area and very intense in the central par of the deposit. The silicification was gradational from margin to center, but for convenience of discussion the deposit has been divided, as shown in Figures 21 and 22, into three zones—an outer zone of slightly altered granite, an intermediate zone o

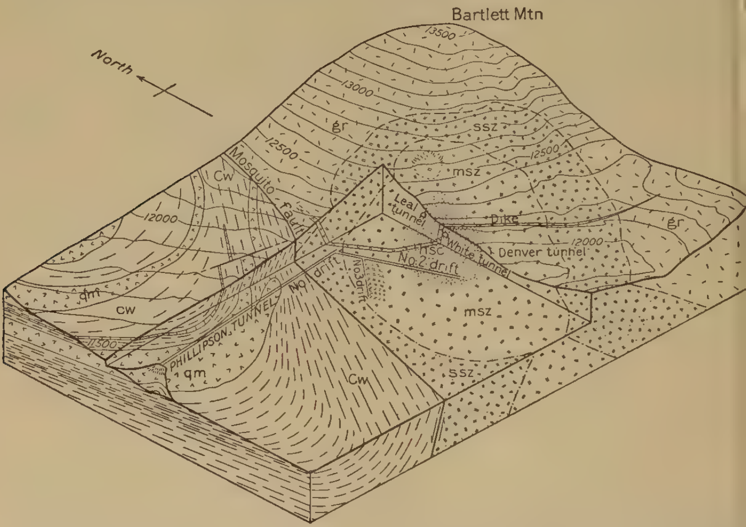


FIGURE 22.—Block diagram showing the detailed relations of the principa zones at Climax. gr, Pre-Cambrian granite; Cw, Carboniferous grits; qm quartz monzonite (Tertiary); hsc, highly silicified core; msz, moderately sili cified zone; ssz, slightly silicified zone. Contour interval 100 feet; datum mean sea level

moderately silicified granite, and an inner core of highly silicifie granite. The chemical changes involved are shown in Figur 23, which is based on chemical analyses of fresh granite, slightl silicified granite, and moderately silicified granite.

In the outer zone the most conspicuous changes of the granit are bleaching of the biotite, sericitization of the plagioclases, an the development of pyrite and abundant secondary orthoclase Pyrite veins with quartz and topaz and scattered quartz vein that contain a little fine-grained molybdenite are present. Th granitoid texture and structure are intact, however, and the roc is easily recognized as a granite.

The intermediate or moderately silicified zone is about 500 feet (152 meters) wide and contains almost all of the developed ore. This zone differs from the outer shell in a decrease of sericite, more intense silicification, and an increase of secondary orthoclase and veinlets. Veinlets of quartz, many containing molybdenite, are more numerous in this zone than in the outer zone or in the core. The molybdenite-bearing veinlets are cut by conspicuous though relatively few veinlets containing quartz, pyrite, and topaz. The appearance of the rock is much changed by the combined effect of the general alteration and the numerous veinlets that are present. However, the outlines of original rock fragments are conspicuous, although in places textures are so modified that granite, schist, and quartz porphyry can not be differentiated.

The central core or zone is essentially massive quartz showing in places only faint "shadows" of the original rock fragments. On the White level this core is 800 to 1,000 feet (244 to 305 meters) across, and on the Phillipson tunnel level it is at least 400 to 500 feet (122 to 152 meters) larger. The change from the intermediate zone to this core generally takes place within 50 feet (15 meters). The molybdenite commonly decreases to less than 0.1 per cent, although in places along the margin of the core the highly silicified rock contains enough molybdenite to be classed as ore. Pyrite occurs in scattered grains and in later veins that have a coarser grain and therefore are more conspicuous but probably not more abundant than in the surrounding zones. The massive quartz is probably formed by coalescing of the numerous veins so characteristic of the outer zones.

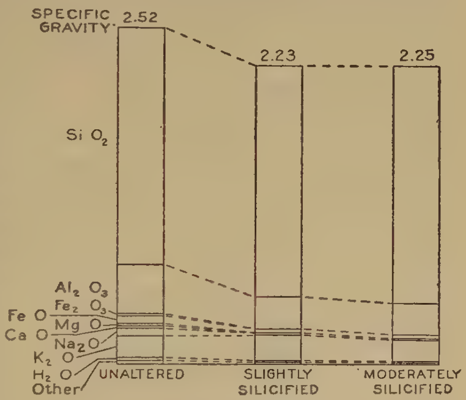


FIGURE 23.—Oxides, in grams per cubic centimeter, in altered and unaltered Silver Plume granite from the Climax district. (From Colorado Sci. Soc. Proc., vol. 12, p. 339, 1931)

The description given is idealized, for areas of moderately silicified rock are found within the highly silicified core, and extensions of the core into the moderately silicified rock are found. The zones are clearly defined, but their boundaries are not and

doubtless would be mapped somewhat differently by different individuals, or even by the same individual at different times.

Nature and extent of the ore zone.—The ore zone is estimated to be 250 to 400 feet (76 to 122 meters) thick. It occurs with fair continuity in the intermediate zone, generally in the inner half adjacent to and in places partly inside the highly silicified core. The depth to which ore extends is not known, but it has been developed in one place by diamond drilling to a depth of about 500 feet (152 meters) below the Phillipson level. The deepest ore is 1,300 feet (396 meters) below the highest outcrops left by glaciation. The character of the ore does not appear to change through this range. The molybdenite is found in numerous quartz veinlets, some of which contain orthoclase or fluorite, and in places a little sericite may also be present. The veinlets are generally less than a quarter of an inch (0.6 centimeter) and rarely more than three-quarters of an inch (1.8 centimeters) thick. They cut the rock in all directions, and in many places it is impossible to find a cubic inch of rock free from one or more veinlets. In the direction of the outer zone the molybdenite content decreases because the molybdenite-bearing veinlets are less numerous and the amount of molybdenite in each veinlet is also less. In the direction of the inner core, generally in an interval of 50 feet (15 meters) or less, the quartz veinlets merge, forming massive quartz, which contains only a few molybdenite veinlets or joints coated with molybdenite.

Figure 24 shows graphically the gradual increase of molybdenite content from the outer zone to ore in the intermediate zone and the abrupt decrease of molybdenite at the boundary of the inner highly silicified core. Phillipson No. 2 drift (shown in fig. 22) is the only place where such a complete section of the ore zone had been opened in 1931 by mine development. However, this poorly defined outer boundary and relatively well defined inner boundary of the ore zone have been observed separately at several places in the mine.

Mineralogy.—The primary minerals occurring at Climax are chalcopyrite, fluorite, hübnerite, molybdenite, orthoclase, pyrite, quartz, sericite, sphalerite, and topaz.

The molybdenite occurs exclusively in quartz veins that may or may not contain orthoclase, and a little was observed in the sericite-bearing fissures. Individual grains average only a fraction of a millimeter in diameter. The molybdenite is primary; enrichment has not taken place.

Veinlets containing pyrite, sphalerite, chalcopyrite, and hübnerite with quartz and topaz cut the molybdenite veinlets and in places are abundant in all three of the zones described. The hübnerite occurs in small blades in and along the vein

walls. Pyrite usually makes up the bulk of these veinlets with the other sulphides and silicates along the central portions. With the exception of topaz, which is fine grained and resembles quartz, these minerals are conspicuous in the Phillipson tunnel.

Sericite is widespread in the mineralized area. It is abundant in the outer zone, where only slight alteration has occurred, but

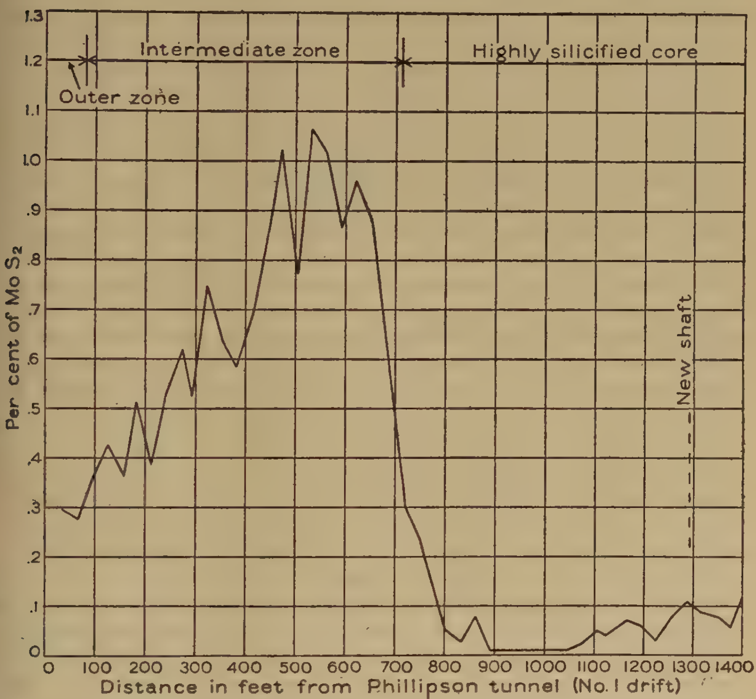


FIGURE 24.—Molybdenite in the Phillipson No. 2 drift. Shows gradual increase of molybdenite content from the outer zone into the intermediate zone and the abrupt decrease of molybdenite content at the boundary of the highly silicified core. Plotted by averaging three assays at 10-foot intervals

is most conspicuous in fissures, where it appears to have been deposited as a phase of the last stage of mineralization.

In addition to the primary minerals there are limonite, jarosite, and molybdite. Limonite, which stains the rocks at the surface, is not found in the mine except along watercourses. Jarosite is common along joints and seams throughout the mine. Molybdite or molybdic ocher is conspicuous in places but is mostly confined to a thin surface zone.

Origin.—The mineralizing solutions are assumed to have come from an intrusive center of Tertiary age which is not represented by any outcropping stocks in or near the area. The temperature of formation is also indefinite, as the associated minerals have a long range of deposition. Molybdenite itself is known to occur as a primary sulphide in pegmatite and therefore presumably is a high-temperature mineral, but it is found also in lead deposits formed at relatively low temperatures. The topaz perhaps indicates a moderately high temperature but does not alone give any clear indication of the conditions under which this deposit was formed.

In the products of rock alteration, particularly the abundant secondary orthoclase, the Climax deposit resembles the disseminated copper deposits at Ely, Nevada, and Bingham, Utah, which are considered mesothermal as defined by Lindgren. Both these copper deposits contain small amounts of molybdenite, which is a further indication of similar conditions of formation. The molybdenite deposit at Shakan, Alaska, except for its content of late zeolites, is also similar to the Climax deposit and is considered mesothermal. It would seem justifiable to assume that the molybdenite at Climax was deposited under the conditions represented in the deposits cited—that is, in the mesothermal zone or the transitional part of the hypothermal and mesothermal zones.

It is not clear why mineralization occurred in the particular area where the molybdenite is now found. In the Climax area there has undoubtedly been a good deal of fissuring of the pre-Cambrian rocks, as is evident from their highly fractured condition outside the ore zone. There has also been shearing in some of the Tertiary dikes, and the shear zones thus produced are the most highly mineralized. The "breccia" appearance of the ore is produced by veining along fractures developed and accumulated in the granite during its long geologic history. The numerous quartz veins suggest a localized brecciation, which is more apparent than real. It is not evident that the rocks in the mineralized area were more broken than those in any of the adjoining portions of the pre-Cambrian granite.

ROAD LOG—CONTINUED

From Climax to a point 3 miles (4.8 kilometers) beyond Kokomo the bedrock is made up of Pennsylvanian and Permian sediments, which dip northeast. At 14.8 miles (23.8 kilometers) from Leadville some of the dark Pennsylvanian shales are exposed in a prospect pit. Red micaceous beds typical of the Permian are exposed a short distance south of Kokomo on the

right-hand side of the road, at 16.9 and 17.7 miles (27.2 and 28.5 kilometers). From Climax to Kokomo the road runs nearly parallel to the Mosquito fault, which forms the east side of the valley near the base of the mountains. This fault has brought the pre-Cambrian granite on the east into contact with the Permian sediments on the west.

Kokomo and the abandoned town of Robinson, 1½ miles (2.4 kilometers) to the south, were formerly important shipping points in the Tenmile district. The ore deposits occur in Pennsylvanian and Permian sediments west of the Mosquito fault. Near Kokomo the chief deposits were great pyritic lead-zinc-silver replacement deposits in Permian limestone below a shale roof. The sediments are cut by dikes and two or more stocks of quartz monzonite porphyry, and innumerable sheets of porphyry have been intruded along bedding planes. Near Robinson the most productive ore bodies occurred along faults in the limestone as veins just below shale beds, but some ore has been mined in sheeted zones in quartzite and porphyry sills. Large bodies of pyrrhotite and pyrite, containing a low content of gold, silver, lead, and zinc still remain in this region, and doubtless development will uncover some of the higher-grade lead-silver ores with some gold, such as were mined between 1879 and 1900.

The road bends northeast at Kokomo and crosses the northward-trending fault about 3 miles (4.8 kilometers) from the town. From this point to the mouth of the canyon near Frisco, the bedrocks are pre-Cambrian schist and gneiss, cut by small bodies of pegmatite and granite. The schists have been in part resorbed by a highly acidic magma and show all gradations from chlorite schist to granite gneiss. At 34.8 miles (56 kilometers) is the junction of the Breckenridge-Dillon road, on the outskirts of Dillon.

(Excursion 3 turns to the left through the town of Dillon and follows the highway leading eastward toward Keystone and Montezuma. After crossing terraces of outwash gravel at 36.4 miles (58.6 kilometers), 1 mile (1.6 kilometers) east of Dillon, the road enters the small gorge cut through the crest of an anticline in Dakota (?) quartzite. At 38.1 miles (61.3 kilometers) the road passes out of the anticline through the Dakota (?) quartzite and enters the Benton shale. From this point to Keystone the Cretaceous beds dip uniformly 25°–30° NE. The ridges that extend south and northwest from Keystone are held up by the pre-Cambrian rock, which has been faulted onto the underlying Cretaceous shales. (See fig. 25.)

At 38.8 miles (62.4 kilometers), where the road crosses the railroad tracks, the dissected terminal moraine of the Snake River

FIGURE 25.—Cross section from Dillon to Lenawee Mountain. Qa, Recent alluvium; Qg, Pleistocene till; KTmp, Eocene quartz monzonite porphyry; Kp, Pierre shale (Cretaceous); Kn, Niobrara formation (Cretaceous); Kb, Benton shale (Cretaceous); Kd, Dakota (?) sandstone (Cretaceous); Km, Morrison formation (Cretaceous?); Cp, Permian red beds; Ag, Silver Plume granite (Algonkian?); As, schist and gneiss (Algonkian?), including Idaho Springs formation

glacier is only a short distance to the right. At 39.7 miles (63.9 kilometers) the road crosses the Williams Range thrust fault, which is concealed beneath glacial drift at the bottom of the valley. From 39.7 to 42.2 miles (63.9 to 67.9 kilometers) the road crosses a ground moraine of the Snake River glacier, of Wisconsin age. The pre-Cambrian rocks are visible on the right-hand side, and the high bench on the left across the river formed by early Pleistocene glaciation is clearly visible in many places. After crossing the Snake River at 42.2 miles (67.9 kilometers) the road bends to the right (east), and within a short distance black silicified Upper Cretaceous shales appear beneath the pre-Cambrian rocks that cap Porcupine Ridge on the left. These shales are well exposed in this "window" through the thrust fault for more than 1 mile (1.6 kilometers). At 43.6 miles (70.2 kilometers) both pre-Cambrian and Cretaceous rocks are cut by Eocene quartz monzonite porphyry locally called Montezuma granite. From this place excursion 3 retraces its way to Dillon, the mileage being set at 34.8 (56 kilometers) at the junction of the Breckenridge road.)

From Dillon to Breckenridge the road crosses the outwash gravel of the Wisconsin glacier, whose terminal moraine blocks the valley about 1 mile (1.6 kilometers) south of Breckenridge. The hills at the left side of the valley for the first 5 miles (8 kilometers) are chiefly quartz monzonite porphyry, though a few small masses of the Upper Cretaceous shales are present along the sides and are visible from the road. The hills at the right (west) are chiefly gravel-covered areas of Dakota (?) quartzite.

At 39.8 miles (64.1 kilometers) the north end of the gravel dredged for gold is reached. On both the Swan River (to the left) and the Blue River (straight ahead) the outwash gravel has been dredged for many miles. The gravel is from 30 to 75 feet (9 to 23 meters) deep and contains from 9 to 20 cents worth of gold to the ton (2.82 to 6.42 grams to the metric ton) in most of the region dredged. Close to Farncomb Hill, the source of much of the gold in the Swan River placers, the material dredged contained much more gold. The road continues through the dredgings to Breckenridge, at 43.6 miles (70.2 kilometers).

Breckenridge is the shipping point for the zinc, lead, silver, and gold ores of the mines east of the town. In the Breckenridge district the sedimentary section, which overlies the pre-Cambrian schists and gneisses unconformably, comprises Permian red beds, variegated shales and sandstones of the Morrison formation, the Dakota (?) quartzite, the Benton shale, the Niobrara limestone, and the Pierre shale. These rocks are cut by early Eocene diorite, monzonite, and quartz monzonite porphyries. The diorite and monzonite porphyries occur chiefly as sills in the shales overlying and underlying the Dakota (?) quartzite. Some of the sills have a thickness of more than 1,000 feet (305 meters). Stocks and dikes of coarse-grained monzonite porphyry cut the monzonite porphyry. Near stocks of the quartz monzonite porphyry limy sediments of the Morrison and Niobrara have been changed to garnetiferous hornstone, but the associated ores are of no commercial value.

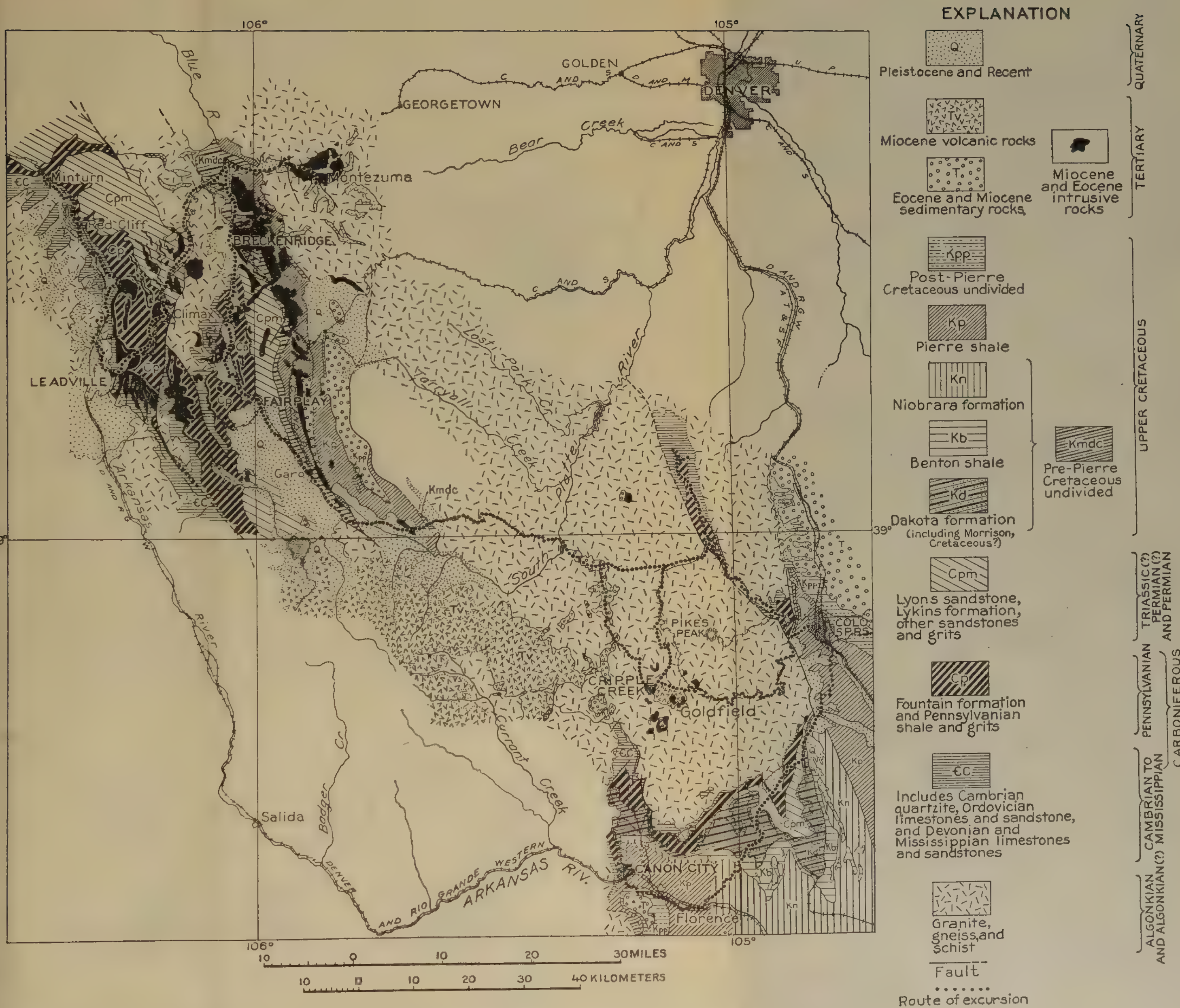
Most of the primary ore mined in the region has come from northeastward-trending veins that follow faults of small throw. The largest ore bodies occur between walls of porphyry or Dakota (?) quartzite, but some profitable shoots have been found in the Cretaceous shales. Much of the production of the district has come from zinc-lead-silver-gold veins within a few miles of Breckenridge, and the most productive veins of this type are those of the Wellington mine, in French Gulch. High-grade silver-gold replacement deposits in Dakota (?) quartzite have been mined. The Breckenridge ore deposits also include stockworks and associated veins containing gold, silver, and lead, found chiefly in monzonite porphyry and Dakota (?) quartzite.

The thin, exceptionally high-grade gold veins of Farncomb Hill, famous for their fine specimens of crystallized gold, cut the Pierre shale. Enrichment has greatly enhanced the value of the ore deposits of the Breckenridge district. Most of the deposits worked primarily for gold have ceased to be profitable below the oxidized zone, which is nowhere more than 400 feet (122 meters) deep. The bulk of the zinc and lead output has come from primary deposits consisting chiefly of iron-bearing zinc blende (marmatite), galena, and pyrite. The chief gangue mineral is siderite, which is abundant in the altered wall rock near the larger veins. Quartz and late calcite are also common. Gold placers have been one of the principal sources of gold.

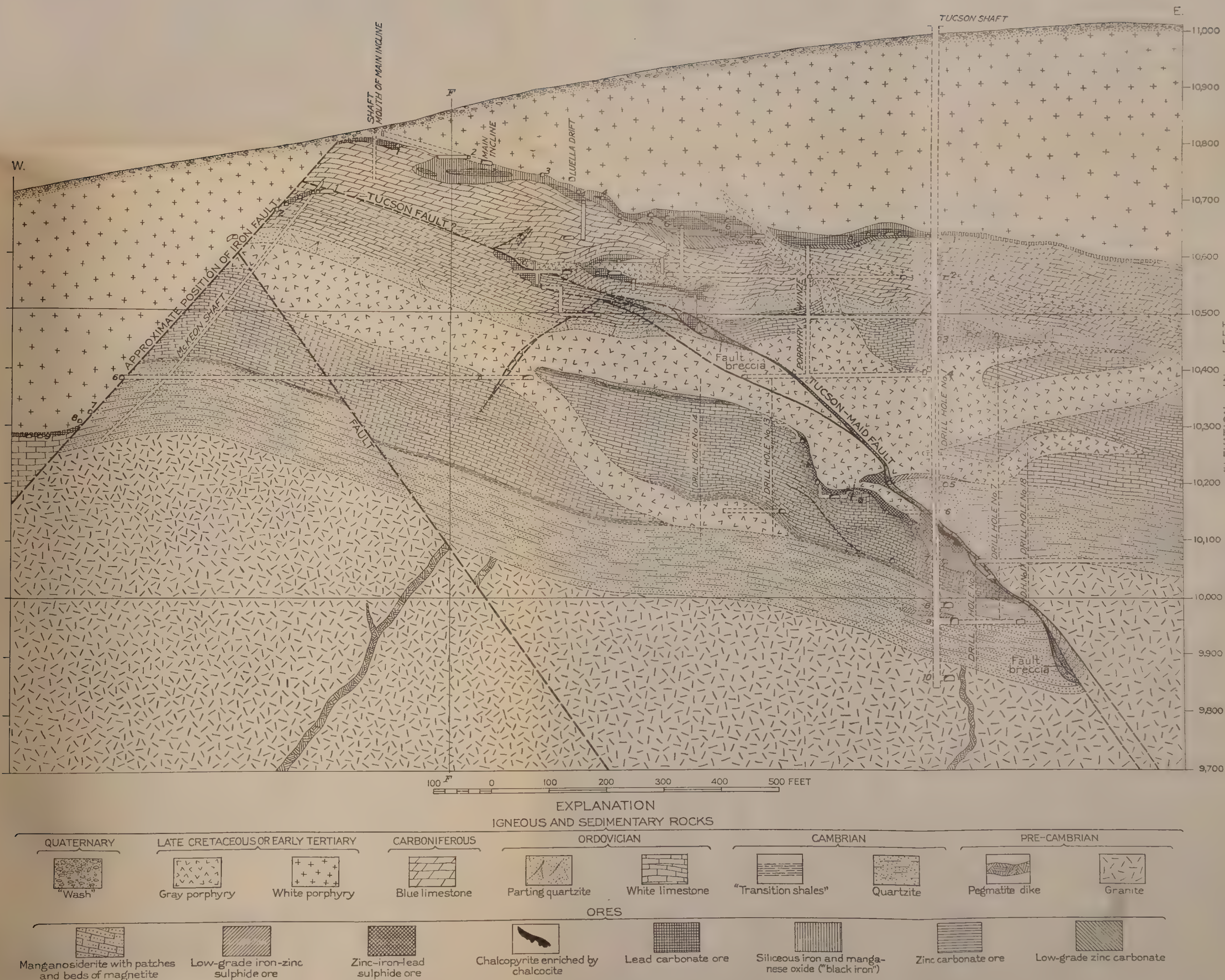
The road continues through Breckenridge, leaving the town at 44.5 miles (71.6 kilometers), and climbs on to the terminal moraine of a Wisconsin ice sheet. Thence to the Governor mine, at 51.1 miles (82.2 kilometers), the road is in a ground moraine. This mine has produced some high-grade lead-silver ore from the Pennsylvanian shales and grits.

From the Governor mine to Hoosier Pass there are many exposures of dark-green and maroon Pennsylvanian shales in the road cut. Hoosier Pass, on the Continental Divide at 55.1 miles (88.7 kilometers), has an altitude of 11,543 feet (3,518 meters).

At 56.4 miles (90.8 kilometers) there is a good view of the glaciated portion of the Platte River Valley. An unconformity between the pre-Cambrian schist and the Sawatch quartzite is visible on Mount Lincoln, across the gulch, and a good example of a rock glacier is also visible on the north slope of Mount Lincoln. After passing through a sill of quartz monzonite porphyry, the road descends through Pennsylvanian shales to the foot of Hoosier Pass, where, at 57 miles (91.7 kilometers), it swings sharply back along the bottom of the Platte Valley. About 500 feet (152 meters) to the right of this point, trilobite-bearing Cambrian quartzite has been thrown out on the dump of a prospect. Three tenths of a mile (0.5 kilometers) farther down the road a good section of the Cambrian Sawatch quartzite and the Ordovician limestone can be seen by walking a short distance farther south to a small gulch which has been cut in these sediments by the Platte River. From this point to Alma the road is on ground moraine most of the way, but a few outcrops of Pennsylvanian limestone may be seen at the left. The many ponds in the stream at the right are caused by beaver dams, and several of their houses are visible. Although protected by law, the beavers remain extremely shy and are rarely seen. At 62.7 miles (101 kilometers) the town of Alma is reached. It is supported chiefly by the gold and silver-lead mines, which are situated in gulches to the west. A short description of the geology and ore deposits of the Alma district is given below.

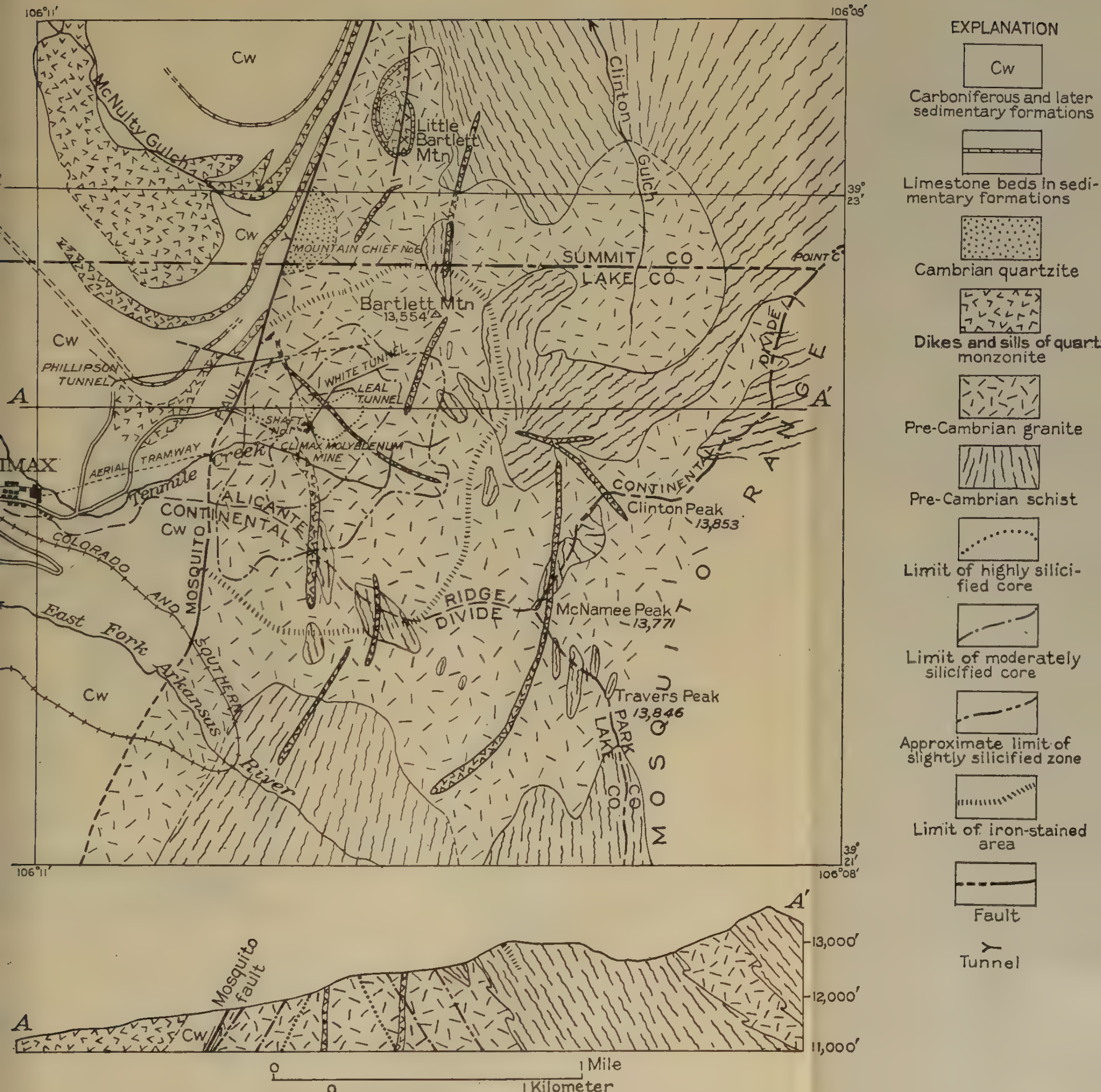


GEOLOGIC MAP SHOWING ROUTE OF EXCURSIONS 2 AND 3 FROM MINTURN TO COLORADO SPRINGS



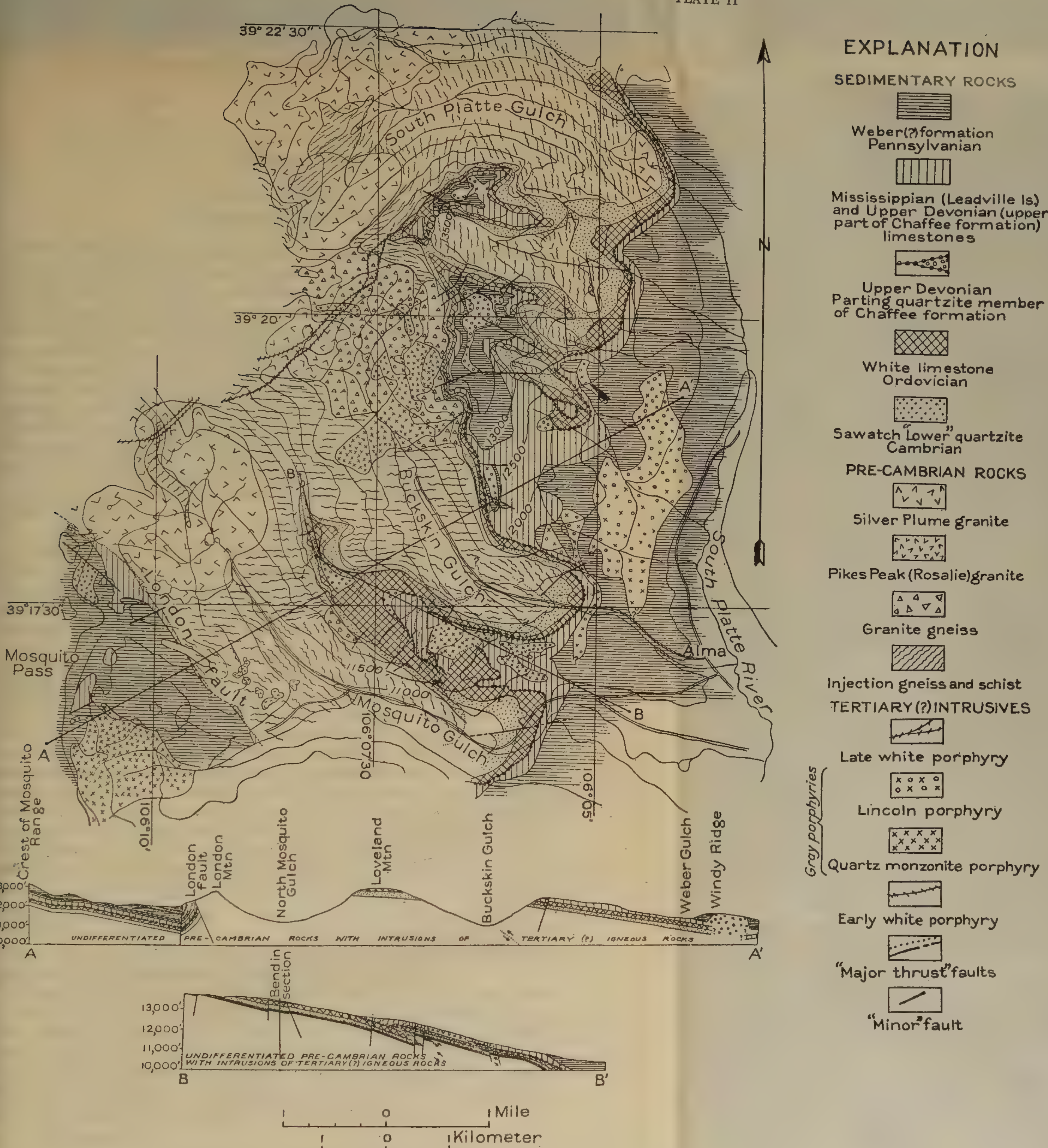
CROSS SECTION THROUGH TUCSON SHAFT SHOWING TUCSON-MAID FAULT

By F. A. Aicher. (From U. S. Geol. Survey Prof. Paper 148, fig. 18, 1927.)



GEOLOGIC MAP AND CROSS SECTION OF CLIMAX DISTRICT

By B. S. Butler and J. W. Vanderwilt. Based on United States Geological Survey topographic map of Climax mining district. (From Colorado Sci. Soc. Proc., vol. 12, p. 332, 1931.)



GENERALIZED GEOLOGIC AND TOPOGRAPHIC MAP OF ALMA DISTRICT

ALMA DISTRICT

By Quentin D. Singewald

Ore deposits have been found at many places along the east slope of the Mosquito Range in an area extending from Fourmile Creek, west of Fairplay, northward to the Continental Divide, chiefly southwest, west, and northwest of the town of Alma, which is 5½ miles (8.8 kilometers) north of Fairplay. The total production is roughly estimated at a little less than $20,000,000.

Near the crest of the Mosquito Range glacial cirques, hanging valleys, and sharp ridges produce a very rugged topography having a relief of several thousand feet. East of this highly dissected portion a few small streams that flow in steep-sided, U-shaped valleys cut through a moderately smooth upland that slopes eastward to the valley of the South Platte River.

Plate 11 is a generalized topographic and geologic map of the Alma district.

GEOLOGY

Pre-Cambrian rocks.—Injection gneiss, quartz-mica schist, granite, granite gneiss, and pegmatite are the most abundant of the pre-Cambrian rocks exposed in the Alma district. The schist has been so permeated by granitic and pegmatitic juices that almost everywhere it has been transformed into an injection gneiss. Two types of granite are intrusive into the schist. The predominant type is a light-gray biotite-muscovite granite which occurs in moderate-sized intrusive masses near the head of several gulches and in small intrusive masses elsewhere. It is believed to be the Silver Plume granite. The other type is a coarse-grained, usually pinkish biotite or biotite-muscovite granite containing a profusion of idiomorphic tabular orthoclase grains that are so oriented as to give the rock a trachytoidal texture. This type, which occurs in several small intrusive masses near London Mountain and elsewhere, is believed to be the Pikes Peak ("Rosalie") granite. The pegmatites are genetically related to the granites. The granite gneiss is believed to be the same as the granite gneiss at Idaho Springs, which Lovering regards as an early aplitic facies of the Silver Plume granite.

Paleozoic sedimentary rocks.—The sedimentary rocks of the Alma district range from Cambrian to Pennsylvanian. The distribution of formations is shown on Plate 11.

Tertiary(?) igneous rocks.—Igneous rocks of late Cretaceous or early Tertiary age occur extensively as dikes and small stock-like masses in the pre-Cambrian rocks and as sills, laccoliths, and, locally, dikes in the sedimentary rocks. They may be divided into several rock types of slightly different age, but all were derived from a single magma reservoir. The distribution of a few of the largest masses is shown on Plate 11.

Classification of the Tertiary(?) igneous rocks of the Alma district arranged according to age

		Characteristic megascopic appearance	Distinguishing features
Late white porphyry		In places shows sheeted structure; soft and compact whitish-gray groundmass; rare to fairly numerous phenocrysts of quartz, biotite, and feldspar.	Some varieties distinguishable from early white porphyry by means of feldspar phenocrysts; other varieties indistinguishable.
Gray porphyry group	Lincoln porphyry	Medium-gray groundmass; numerous medium-sized phenocrysts of plagioclase, quartz, and biotite and scattered pink euhedral orthoclase crystals, half an inch (1.2 centimeters) to several inches in length.	Large pink orthoclase crystals.
	Quartz monzonite porphyry.	As a rule considerably altered; medium greenish-gray groundmass; numerous phenocrysts of plagioclase, hornblende, biotite, and quartz.	Altered appearance, medium color, abundance of visible quartz, sparsity of hornblende.
	Monzonitic diorite porphyry.	Usually has fresh appearance; dark-gray groundmass; numerous phenocrysts of plagioclase, hornblende, biotite, and quartz.	Fresh appearance, dark color, abundance of hornblende, sparsity of visible quartz.
Early white porphyry		Soft and compact whitish-gray groundmass; extremely rare phenocrysts of quartz and biotite.	

Structure.—The sedimentary strata dip about 15° in a direction a little south of east, and there are numerous faults. Departures from the normal dip are found near the thrust faults and in the Windy Ridge area.

The faults may be divided into two main groups—major thrust faults, which are not numerous, and minor faults, which are so numerous that only a few can be shown on Plate 11. Most of the minor faults are normal, and they die out within short distances both horizontally and vertically. Throughout most of the district their prevailing trend is northeast, but in the area around Mount Lincoln and Mount Cameron it is northwest.

The age relations of the faults to the Tertiary(?) intrusives and to the ore mineralization are shown in Figure 26.

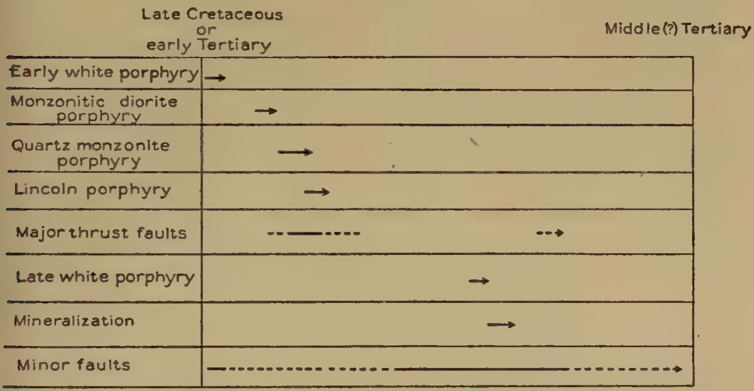


FIGURE 26.—Age relations of faults, Tertiary intrusives, and mineralization in the Alma district. Length and position of arrows indicate relative time

Ore deposits.—Very soon after the intrusion of the late white porphyry ascending magmatic solutions derived from the same reservoir as the porphyries formed veins along fissures and at many places replaced the adjoining wall rock. The major thrust faults are not mineralized to any extent, but they appear to have localized many of the ore bodies near them. Apparently they themselves were sealed with clay gouge but were accompanied by numerous subsidiary fissures that were not sealed. The premineral minor faults served as the immediate channels of circulation, and veins formed along them.

Deposits of commercial importance have been found in the quartzite member of the Cambrian Sawatch formation, the Ordovician "White" limestone, and the Mississippian Leadville limestone, but not in the other sedimentary formations. Only

a few have been found in the pre-Cambrian rocks, and most of these are confined to the Silver Plume granite.

On the whole, the ores are characterized by a simple mineralogy. At many places oxidation has partly changed the hypogene minerals to new compounds and has caused enrichment. The most abundant ore minerals are pyrite, sphalerite, galena, and chalcopyrite. At some places tetrahedrite, ruby silver, native gold, and native silver are common, but other minerals are unimportant. The chief gangue minerals are quartz, ankerite, dolomite, and barite. Adjoining the deposits the wall rocks, especially the porphyries, are intensely altered, but a considerable part of the alteration of the porphyries occurred as an end phase of igneous intrusion before ore mineralization started.

As measured by past production, the most valuable deposits are the silver-lead ores like those of the Moose, Dolly Varden, and Russia mines. They occur as replacement deposits in the upper part of the Leadville or "Blue" limestone, where the upward migration of the solutions was checked by the impervious Weber(?) shale. The blanketlike ore shoots are extremely irregular in directions parallel to the bedding, but many show a general alinement close to prominent fissures. The hypogene ores consist of argentiferous and slightly auriferous base-metal sulphides in an ankerite-barite-quartz gangue; they are partly oxidized and enriched. Similar deposits at lower stratigraphic horizons are of less importance. In the Hock Hocking mine partly oxidized ores that in a few places contain wire silver occur in the upper part of the "White" limestone below a lenticular bed of shale; these ores are essentially veins adjoining which the wall rock is replaced to a distance nowhere exceeding 15 feet (4.5 meters).

Second in importance are the gold-quartz veins of the London mine, the largest and most productive single mine in the district. They occur in fissures that dip steeply to the west, nearly parallel to the dip of the interbedded sedimentary rocks and intruded sills, where these strata are sharply upturned against the west side of the London fault. The London fault has a displacement of about 3,000 feet (914 meters) and dips steeply to the east. The mine workings cut the Leadville limestone, the Weber(?) formation, and thick sills of early white porphyry and bleached quartz monzonite porphyry which were intruded very close to the base of the Weber(?) formation. From one to four discontinuous, nearly parallel veins occur at the contact of the two porphyries, at the contact of one of the porphyries with the Weber(?) formation, or within one of the porphyries. The ore

consists of rather coarse quartz, much of which has comb structure, minor sulphides, and free gold.

Third in importance are a group of ore bodies found in the quartzite member of the Sawatch formation, such as those of the Orphan Boy, Phillips, and Paris mines. Their principal value is in gold, but they contain silver and in places zinc, lead, and copper. They were formed as veins along fissures, but owing to replacement the veins extend with irregular boundaries for several feet into the wall rock. The only abundant hypogene minerals are dolomite, quartz, pyrite, sphalerite, galena, and chalcopyrite. Much of the dolomite contains numerous vugs. Most of the ore bodies are partly oxidized; a few of them have been so thoroughly leached as to leave caves large enough to walk through. A spongy limonite "dirt" containing variable amounts of gold and a little silver is the product of complete leaching.

ROAD LOG—CONTINUED

The glacial moraine east of Alma has been washed for gold by hydraulic monitors. The road continues south from Alma on ground moraine to mile 67.5 (108.6 kilometers), where it climbs over the terminal moraine and descends into Fairplay. The outwash gravel below this moraine contained much more gold than the ground moraine and was successfully worked by a dredge for a few years.

The route enters Fairplay at 68.3 miles (110 kilometers), and the mileage is set back to zero. The cars follow the main highway from Fairplay to Florissant by way of Hartzel and Lake George. After crossing the Platte River, just south of Fairplay, the road ascends the outwash-gravel terrace and turns southeast across its nearly level surface. The conspicuous ridge about 3 miles (4.8 kilometers) east of Fairplay is a "hogback" held up by Dakota (?) sandstone. The reddish ridge on the right (west) is a Permian sandstone beveled by an early Pleistocene terrace. At 5.5 miles (8.9 kilometers) the road crosses a railroad track and swings to the right along the base of the hogback ridge. As the capping sandstone has the regional northeasterly dip, the underlying Morrison formation is exposed along the steep western slope of the ridge.

The road follows the base close to the contact of the Permian sandstones and the Morrison formation for many miles. The basal sandstone of the Morrison formation is well exposed from 8.5 to 9 miles (13.7 to 14.5 kilometers). For most of the way from Garo, at 10.7 miles (17.2 kilometers), to Hartzel the road is in Permian beds near the west base of the Dakota (?) hogback,

which is from 500 to 5,000 feet (152 to 1,524 meters) east of the road. At 15.5 miles (24.9 kilometers) the white reef of Permian algal limestone may be seen about 1,500 feet (457 meters) to the left (east). It is overlain and underlain by red micaceous Permian shales.

At 17.9 miles (28.8 kilometers) the road turns west along Fourmile Creek, passing through the hogback at 19.2 miles (30.9 kilometers) into Hartzel.

Pre-Cambrian granite on the south can be seen faulted against the basal Morrison sandstone on the right just before the road enters the town, and the pink shale of the Morrison just north of the upthrown granite is visible across the creek on the right on leaving the town. For the first 5 miles (8 kilometers) out of Hartzel the road skirts several remnants of high-level terraces, and this early Pleistocene surface is also well preserved across the valley on the right.

Andesitic lavas of Miocene age crop out at the left of the road from 24.6 to 25.3 miles (39.6 to 40.7 kilometers). At 27.8 miles (44.7 kilometers), where the road branches, the hill half a mile (0.8 kilometer) to the right is capped by granite that has been thrust over the westward-dipping Pierre shale, of Upper Cretaceous age. The ridge at the left is held up by Dakota (?) sandstone, which dips 15°–30° W. but is faulted against the eastward-dipping Pierre shale, Benton shale, and Niobrara formation, all of Upper Cretaceous age. At 28.5 miles (45.9 kilometers) the road crosses a fault between Cretaceous and pre-Cambrian rocks, but the pre-Cambrian is concealed beneath glacial outwash as far as 32.5 miles (52.3 kilometers). From this point to Lake George the road is in pre-Cambrian rocks. From 32.5 to 41.5 miles (52.3 to 66.8 kilometers) northward-dipping schists and gneisses of the Idaho Springs formation border the road on both sides. At 34.5 miles (55.5 kilometers) is Wilkerson Divide (altitude 9,500 feet, or 2,896 meters). Pikes Peak is visible almost straight ahead, and a good view may be had of the Miocene peneplain, above which the peak rises about 4,000 feet (1,219 meters). A coarse-grained reddish granite, known as the Pikes Peak granite, appears on both sides of the road at 41.5 miles (66.8 kilometers) and is the chief rock seen in the landscape from this point to the mountain front near Colorado Springs. Lake George is reached at 45 miles (72.4 kilometers). Along the "old road" to Florissant gray shales of the Florissant lake beds, of Miocene age, crop out in cuts at the side of the road at many places. The lake beds at 48.5 miles (78.1 kilometers) contain abundant plant remains and some insects. Florissant is reached at 50.1 miles (80.6 kilometers).

FLORISSANT TO COLORADO SPRINGS

At Florissant excursions 2 and 3 divide and follow separate routes to Colorado Springs. The route followed by excursion 2 will be given first; that followed by excursion 3 will be found on pages 124–125.

EXCURSION 2

ROAD LOG

Excursion 2 goes from Florissant to Colorado Springs by way of Cripple Creek. The road leading south from Florissant is chiefly in the gray shales of the Florissant lake beds for about 6 miles (9.6 kilometers). In this region the surface has been little modified since Pliocene time and is typical of the so-called peneplain that was developed during the Miocene and Pliocene epochs. The shales are well exposed at many places along the road for the first 4½ miles (7.2 kilometers) out of Florissant. At 57.7 miles (92.9 kilometers) the Pikes Peak granite crops out on the left of the road.

From 58.7 to 59.6 miles (94.5 to 95.9 kilometers) augite andesite lavas of early Miocene age crop out along the road. Pre-Cambrian olivine syenite appears on the right at mile 64.7 (104.1 kilometers) and continues to mile 66.1 (106.4 kilometers), where the bedrock is concealed beneath alluvium and slide rock of Mount Pisgah, on the right, which is capped with phonolite. The ridge at the right from 66.6 to 67.2 miles (107.2 to 108.1 kilometers) is phonolite. At 67.2 miles (108.1 kilometers), where the road passes over the crest of a hill, a good view may be had of Cripple Creek and its mines. The gold telluride veins of the Cripple Creek district are the best known and most productive in Colorado. A brief description of the district is given below.

CRIPPLE CREEK MINING DISTRICT

By G. F. Loughlin

Introduction.—Gold mining in the Cripple Creek district began in 1891 and increased at an accelerating rate, with few interruptions, until 1900; for that year the total value of recovered gold was $18,150,000. Between 1901 and 1917 the output declined, but the annual value remained above $10,000,000. During the next two years, owing in part to war conditions and in part to depletion of the more easily mined and higher-grade ore bodies, recovered production decreased sharply, and since 1920 it has averaged under $4,000,000; in 1929 it was $2,640,000, and in 1930, $2,527,000. The total recovered output (including stolen "high grade" gold) from 1891 to 1930, inclusive, has been—gold, $349,371,000; silver, 1,908,000 ounces (59,345,441 grams).

One of the obstacles to mining since the early days of the district has been the abundance of ground water, which is now disposed of through the Roosevelt drainage tunnel. This tunnel was driven in 1906 to 1910 through the cooperation of the principal mining companies. Its portal is at an altitude of 8,020 feet (2,445 meters), and its length is 24,255 feet (7,393 meters). It lies from 1,200 to 2,100 feet (365 to 640 meters) below the collars of the shafts in its vicinity and drains the most productive part of the district. Only three mines have been extended below the level of this tunnel, the Vindicator for 100 feet (30 meters), the Cresson for about 400 feet (122 meters), and the Portland for about 1,000 feet (305 meters). Pumping from the bottoms of all three of these mines has been discontinued, and the Roosevelt drainage tunnel now marks the limit of deep mining in the district.

Geology.—The mines of the Cripple Creek district are mostly situated within a denuded volcanic neck, composed mainly of phonolite breccia of Miocene age, which forms a group of hills near the eastern border of a much dissected plateau. The surrounding rocks are mainly granites, gneisses, and schists of pre-Cambrian age. They extend over a large area which includes Pikes Peak, more than 14,000 feet (4,267 meters) in altitude, but the general altitude of the plateau is not far from 10,000 feet (3,048 meters).

The volcano occupies a rudely elliptical area more than 4 miles (6.4 kilometers) in maximum length and 2 miles (3.2 kilometers) in width. (See pl. 12.) A volcanic plug of phonolite forming Beacon Hill lies just southwest of the main area, and several dikes of phonolite and alkaline basic rocks are present in the surrounding pre-Cambrian rocks, especially in the vicinity of the phonolite plug. Remnants of tuffs, believed to represent the outermost limits of the original volcano are present on the hills 2 or 3 miles (3.2 to 4.8 kilometers) south of the main area.

The walls of the main neck are steep and irregular but on the whole converge downward, although at a few places they overhang the breccia. The most continuous exposures of the walls are in the Independence, Portland, and Ajax mines (pl. 13), which locally show benches of gentle slope, especially on the upper levels, and also one of the overhanging parts just mentioned.

The neck incloses in its central and western parts two large masses of granite and schist (pl. 12), which are probably continuous with each other and with the pre-Cambrian rocks to the north and west of the neck—in other words, the northwest quarter of the volcanic area is thought to be a minor neck. The prevalence of intrusive masses in the breccia south and east

of the inclosed granite mass indicates that igneous activity was greatest there. This part of the breccia also includes the deepest and most productive mines and appears to be the main neck of the complex mass; but no western wall separating it from the southwest quarter of the area has thus far been disclosed above a depth of 2,000 feet (610 meters).

A small pipe of basaltic breccia cuts the main breccia at the Cresson mine, and some of the largest ore shoots in the district have been mined along its margins. It has been exposed to a depth of more than 2,000 feet (610 meters), and its lower part separates into two prongs or "roots," as shown in Figure 27. The "roots" of this small pipe may be similar in a general way to the different parts of the main neck mentioned in the preceding paragraph.

The rocks of the volcanic neck include, besides the breccias, intrusive dikes and masses of phonolite, latite-phonolite, syenite, and alkaline basaltic rocks. The dikes, especially those of phonolite and basic rock, commonly have a primary sheeted structure, which has rendered them subject to reopening during stages of fissuring and to mineralization.

The main breccia is gray where unaltered, but has been largely, bleached to nearly white. It consists of grains and small fragments of phonolite, with considerable latite-phonolite and locally granite. A little stratification is observable in some places. Large fragments are present, especially near the margins of the neck and near the contacts of some of the larger intrusive masses of latite-phonolite and light-gray syenite. The breccia is the result of several explosive eruptions, the latest of which disrupted some of the earlier dikes and larger intrusive masses. Fragments of carbonized wood have been found more than 1,000 feet (305 meters) below the surface.

The Cresson pipe of basaltic breccia represents one of the latest stages of activity within the main neck. It cuts off dikes of all kinds except the very latest local group of basaltic dikes. It is much darker gray than the breccia of the main mass, except where extremely altered, and consists of coarser material.

The earliest of the distinctly intrusive masses are latite-phonolite, a reddish-gray rock with distinct small white phenocrysts of plagioclase in a dense groundmass. A second variety is light gray and contains tabular phenocrysts of orthoclase, 5 millimeters or more long, in roughly parallel arrangement, and in some places it also contains small vugs lined with specularite. Both varieties form dikes, and the reddish-gray variety also forms sill-like masses and downward-tapering plugs, which are limited mainly to the upper levels of the mines in the southeast quarter of the area.

There are two varieties of syenite—one light gray, somewhat porphyritic, and similar in visible mineral composition to the light-gray variety of latite-phonolite, the other dark gray and even-grained. Both varieties form irregular plugs and dikes.

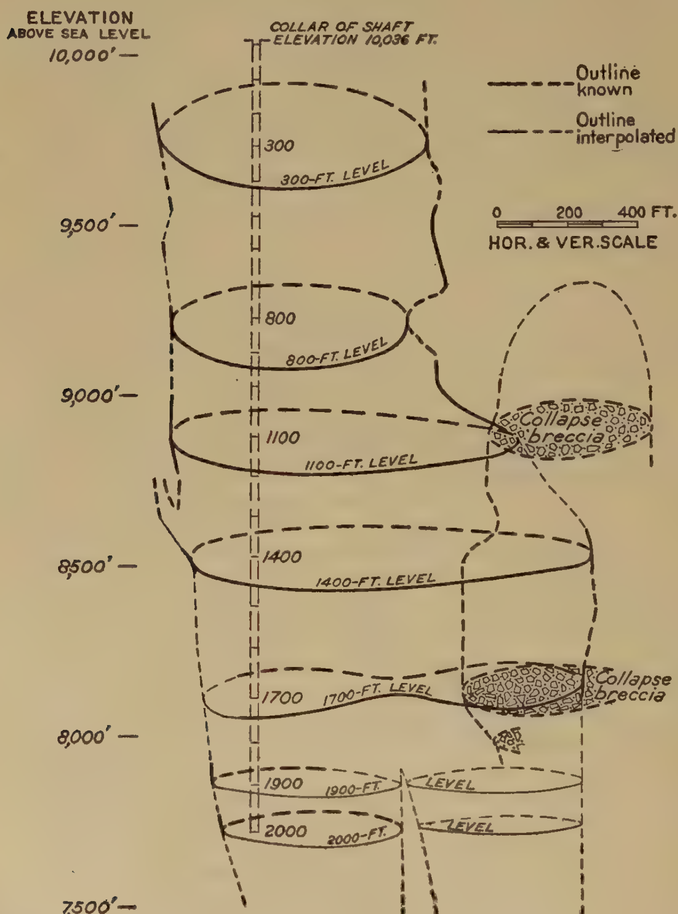


FIGURE 27.—Outline of Cresson pipe of basaltic breccia

There are also two varieties of phonolite—one a dark purple dense rock, relatively scarce, and the other a light gray dense rock, which is widespread and cuts all the other intrusive rocks of the neck except the basic dikes.

The basic dikes include trachydolerite, vogesite, and monchiquite. The trachydolerite forms the large sill-like mass that caps Bull Cliff, and also forms dikes. The other basic rocks form dikes almost entirely, but there are two sill-like masses that cut through the basaltic breccia near the 1,100 and 1,800 foot (335 and 549 meter) levels of the Cresson mine and have formed roofs to large ore shoots.

The dikes and other intrusive masses as a whole indicate at least nine distinct stages of activity intervening between the formation of the main breccia and the deposition of ore, and the basaltic breccia of the Cresson mine represents a tenth stage.

Fissures.—The fissures, including many sheeted zones and a few small faults, have a roughly radial pattern, diverging from a relatively barren area that includes the large, inclosed granite mass; but they also occur in intersecting or conjugate systems. Besides these systems of vertical or steeply dipping fissures there are fissures, called "flats," that are nearly horizontal or dip at angles of less than 45°. Fissuring took place repeatedly, as shown by the sequence of dike intrusions and by the reopening of veins, which were formed during three major stages. Some fissures were persistent planes of weakness and, locally at least, contain two or more dikes as well as veins; others, opened at an early stage, contain only the earlier dikes; still others, opened only during a late stage, contain barren or productive veins unaccompanied by any dikes. It is rather common for the later-formed fissures to trend at small angles to the earlier ones and to be deflected along them.

The intersecting systems of fissures and sheeted zones indicate deformation by compression, the greater part of which is attributed to the intermittent settling of the breccia in the volcanic neck.

The pipe of basaltic breccia in the Cresson mine (fig. 28) affords a good example of fissuring due to slight settling. Both steeply dipping and "flat" fissures and sheeted zones are present. Those of steep dip in part coincide with the boundaries of the pipe but in part are roughly parallel to it and in part at right angles to it. The "flats" are apparently most numerous in the outer parts of the pipe. Those near the hanging wall of the pipe commonly dip toward the boundary, and those near the footwall away from the boundary. Short basaltic dikes locally fill steeply dipping fissures within the pipe and along the boundaries, especially the south boundary. They less commonly fill "flats" but have formed large sill-like masses along them near the 1,100 and 1,800 foot (335 and 549 meter) levels of the mine. The ore bodies are largest and most continuous along the hanging-wall side of the pipe and extend into the interior, especially near the

sill-like mass near the 1,100-foot (335-meter) level, and into the surrounding ground along fissures that extend upward from the boundary of the pipe. The structure as a whole implies slight shrinkage of the mass accompanied by settling into a downward-tapering pipe, with a tendency to drag along the footwall and to develop open fissures along and parallel to the hanging wall.

Fissuring in the main volcanic neck is more complex than that within the Cresson pipe. Irregularities in the walls of the neck and differences in resistance to compression and shearing between the porous breccia and the larger masses of dense latite-phonolite and syenite have introduced many variations from the simple pattern of fissuring that would be expected from the settling of an inverted cone of uniform rock. Regional stresses, however, may have supplemented local stresses. Productive fissures in the adjacent granite may have been formed before or during the earliest stages of volcanic activity and have been reopened later, especially where they coincide in trend with fissures developed in the breccia, as in the Ajax and Portland-Independence ground.

The influence of local conditions on the arrangement of fissures in the main neck is well illustrated by the Portland mine. There the northward and eastward pitch of the wall of the neck (pl. 13) caused a northward settling of the breccia and a shearing along the northward-trending part of the wall. This shearing produced one of the most persistent fissure zones in the district. This zone contains dikes of syenite, phonolite, and basic rock and the main ore shoot of the Portland mine, which has been practically continuous from the surface to a vertical depth of 3,000 feet (914 meters). A short distance north of the granite-breccia contact (fig. 28) movement of this same kind produced local shearing between two closely spaced masses of massive latite-phonolite and an intervening mass of breccia which is cut by a number of closely spaced parallel fractures. At deeper levels, where the two masses of latite-phonolite have diverged and tapered into dikes, the parallel fractures terminate. The ore in them was introduced by a devious course from the main vein, probably along the phonolite dike that extends through No. 2 shaft on the 500-foot (152-meter) level.

Settling has continued to a slight extent, even after ore deposition, and the ore shoots are locally sheared but not appreciably displaced.

Ore deposits.—The ore deposits of the district include (1) fillings of small fissures and sheeted zones in breccia or granite or along dikes and (2) irregular bodies adjacent to fissures and formed by the replacement of country rock. Another kind of

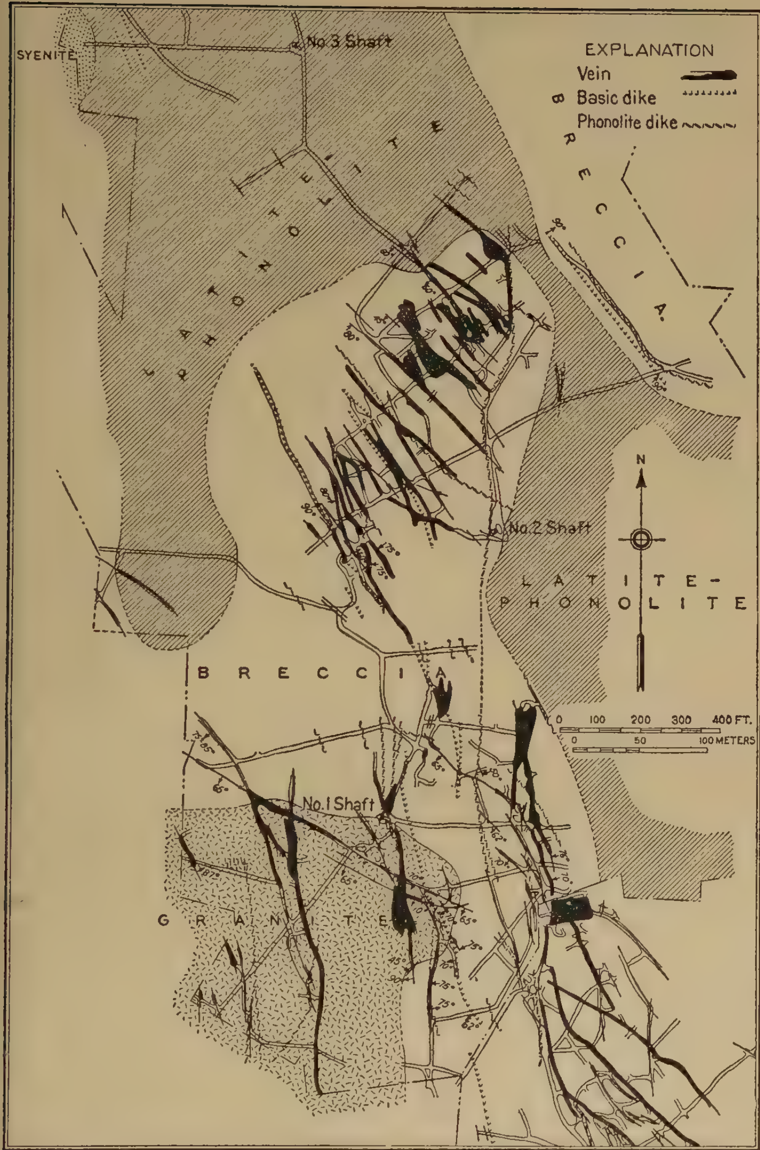


Figure 28.—500-foot level of Portland mine, showing relation of the main vein group, east of No. 1 shaft, to a group of small rich veins to the north, near No. 2 shaft

deposit, but thus far of too low grade to pay for mining, is a collapse breccia with fragments coated by vein minerals. (See fig. 27.) The mineral composition of the ores at deep levels is essentially identical with that of the original ore at higher levels, and the relations of the minerals to one another are also similar.

The order of mineral deposition is conveniently grouped into three stages, each of which could be divided into substages if extreme detail were worth while. The second stage brought gold in commercial quantity. Dense masses of adularia and quartz are among the earliest minerals deposited, but the most conspicuous product of the early stage is dark-purple fine-grained massive fluorspar accompanied by varying quantities of quartz and comparatively coarse-grained pyrite. The quartz is abundant but not conspicuous, as most of it is very fine grained or microscopic and is concealed in the dark massive fluorspar.

This mixture of massive fluorspar and inconspicuous quartz commonly forms solid veins ranging from less than 1 inch to 2 feet (2 centimeters to 0.6 meter) in thickness. Their massive form and uniformly fine grain give them a dikelike aspect. Locally they contain angular fragments of wall rock. Where split or broken by movement along them and especially at intersections with other veins or fissures, these massive veins are likely to contain minerals of the second stage and to be valuable ore shoots, but elsewhere they are of no value.

Deposits of the second stage include the same minerals as those of the first, but the fluorspar is somewhat lighter purple, the quartz milky to somewhat smoky, and the pyrite fine grained and inconspicuous. As these minerals occur mostly in open though narrow cracks and in vugs, their crystal outlines are distinct. Other conspicuous minerals of this stage are dolomite, in small white rhombic crystals; celestite, usually in small slender prisms and radial aggregates; and the gold tellurides, mostly calaverite or sylvanite, which form small prismatic crystals in cracks and vugs and in some places cut or impregnate minerals of the first stage and the adjacent wall rock. Hessite and a few other tellurides are locally present. An occasional grain of free gold accompanies the tellurides of gold, even at deep levels. Roscoelite, the green vanadium mica, is present in some places, especially where veins follow basic dikes. Galena, zinc blende, and locally molybdenite, also belong to the second stage and are present in small quantity near some of the ore shoots. Tetrahedrite has also been reported but may have been confused, in part at least, with an unnamed telluride of copper and silver.

The third stage is represented mainly by smoky to colorless quartz in fine to coarse druses and by yellow chalcedony. Other

minerals of this stage are pyrite in thin druses of either radiating needles or minute pyritohedrons, calcite in small scalenohedrons, locally cinnabar, and rarely minute grains of fluorite. Minerals of the third stage form druses covering ore minerals but are also present in barren places and can not be regarded as a definite indication of ore.

The earliest stage of mineralization began, where most intense, with the solution of wall rock, accompanied by spalling and settling of corroded fragments, especially of the breccia. The fragments became coated and cemented by minerals of the first stage, forming a collapse breccia with large interstices. Where the rock resisted collapse, caverns of considerable size were formed, especially in the basic dike rocks. During the second stage solutions passed so freely through these collapse breccias that although some characteristic gangue minerals were deposited in them the tellurides were mostly carried along farther; but exceptionally, where circulation was hindered, some extremely rich ore shoots were formed, especially in two caverns in the sill-like mass near the 1,100-foot (335-meter) level of the Cresson mine. These caverns became thickly lined with tellurides, while other caverns near by remained barren. Ore deposition took place mainly along fissures and sheeted zones in places near the collapse breccias, and extended considerable distances from them, following the more permeable parts of both steeply dipping fissures and "flats." The course followed was complex in some places, and solutions arising from some of the different local sources evidently coalesced. Deposition took place mainly as the simple filling of fractures and cavities, but there was a little replacement by ore and gangue minerals, and the wall rocks for considerable distances from the veins were impregnated by pyrite and sericite.

The principal local sources of the ore solutions, so far as they have been indicated by deep mining, are in the more persistent fissure zones along which the later stages of settling of the volcanic neck took place. One of the principal sources is associated with the irregular northward-pitching granite wall in the Portland mine and is about vertically below the Last Dollar shaft. It supplied ore not only to these mines but, in part at least, to the mines north and northwest of them. Another important source is beneath the collapse breccia that is associated with the Cresson pipe of basic breccia. It supplied ore to the veins and large replacement deposits along and within that pipe and to some rich deposits in adjacent mines. Solutions from it doubtless coalesced with those from the Portland-Last Dollar source. Other sources near the south margin of the main neck are indicated by collapse breccia in the Big Banta mine and by corroded

and replaced granite in the Ajax and Elkton mines. Still another source is associated with persistent fissures along the contact between the breccia and a complex mass of dark-gray syenite in the Vindicator mine, in the southeast part of the neck. It evidently supplied ore not only to the Vindicator veins but to the Findley and neighboring veins to the north, and solutions from it may also have coalesced with solutions from the Portland-Last Dollar source.

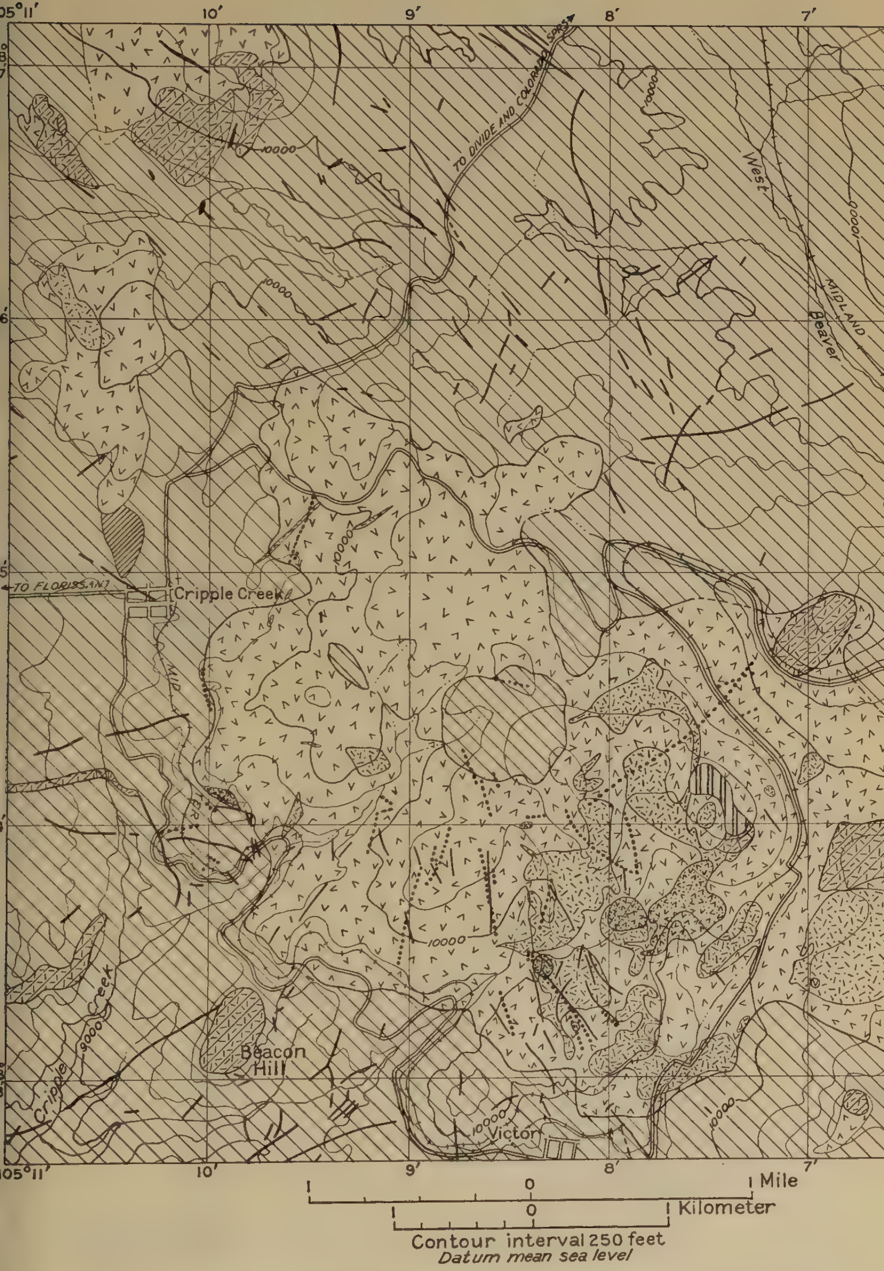
Other sources have not been so clearly indicated, because mine workings related to them have either become inacessible or are too shallow to be very significant. One is evidently associated with the phonolite plug of Beacon Hill, and another with the group of horizontally persistent veins northeast of it. Structural conditions at and near the Abe Lincoln mine, on the west edge of the main neck suggest a minor source worthy of more attention than it has received, and the same is true along the eastern margin of the neck directly north of the large inclosed mass of granite.

Circulation of the ore-forming solutions away from the main fissure zones was complicated. The opportunity for finding open fissures was much greater in the shallow parts of the neck than in the deeper parts, and workable veins have been found to be much more abundant in the shallow parts. Some of these veins pass downward into barren, tight, or gouge-filled fractures, or the fractures themselves terminate downward. The solutions, therefore, must have reached them by horizontal or even locally downward circulation from the main or trunk fissure zones. Lateral exploration from the main veins below a depth of 1,500 feet (457 meters) has disclosed only tight fissures, with here and there small ore shoots of fair to rather high grade, and the hope for deep development is confined to the trunk fissures.

ROAD LOG—CONTINUED

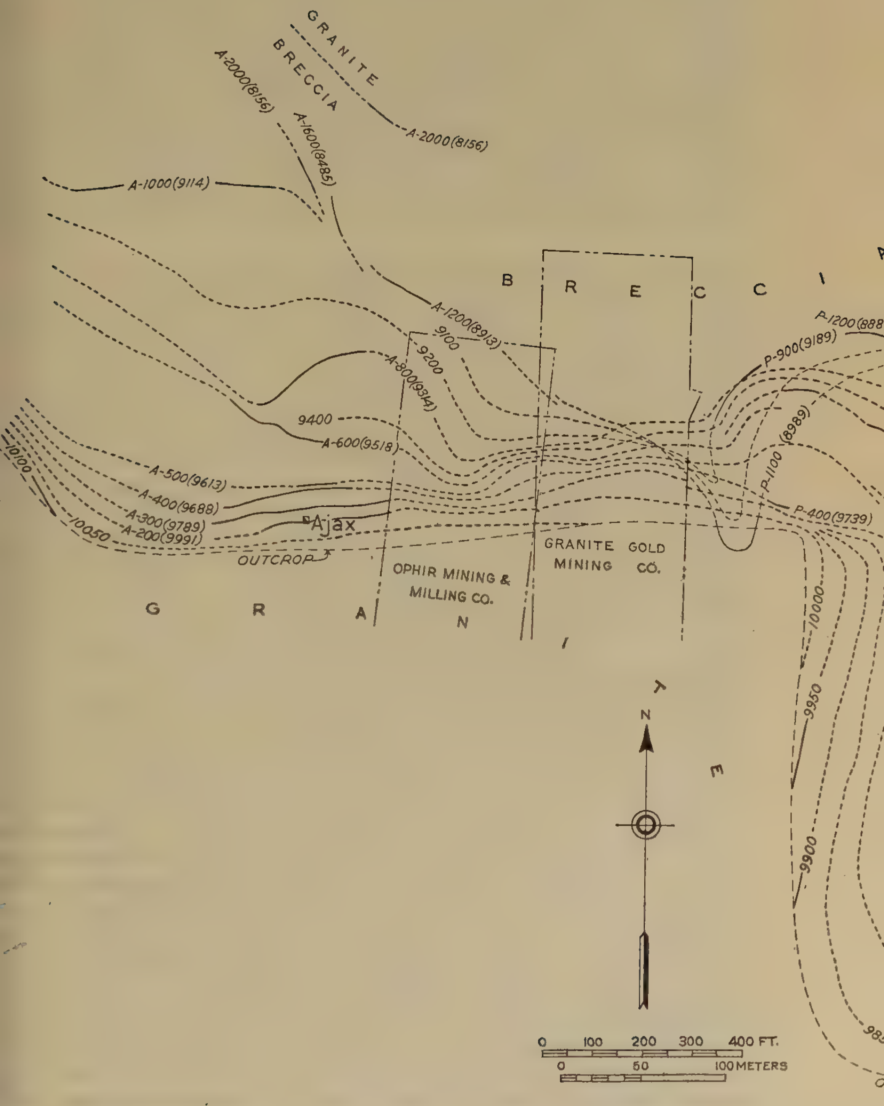
From the east end of the town the main road leads across Cripple Creek granite and Pikes Peak granite to the town of Divide, 18 miles (29 kilometers) north. About half a mile (0.8 kilometer) north of Cripple Creek, at 69.1 miles (111.2 kilometers) the road to the Corley Mountain highway branches to the east and within a short distance leads across the Cripple Creek volcano. At 70 miles (112.7 kilometers), opposite a good outcrop of the volcanic breccia, there is an excellent view of the Sangre de Cristo Range, to the southwest. At 70.6 miles (113.6 kilometers) the road swings to the left across a minor drainage divide and thence to Colorado Springs follows an old railroad grade.

Good exposures of breccia and the latite-phonolite occur in a deep cut where the road turns sharply left at 71.7 miles (115.4



OUTLINE MAP OF CRIPPLE CREEK VOLCANIC AREA

After Ransome and Graton. (U. S. Geol. Survey Prof. Paper 54, pl. 2, 190



PLAN OF GRANITE-BRECCIA CONTACT ON DIFFERENT LEVELS OF IND

(From Am. Inst. Min. Met. Eng. Tech.

kilometers). From this point to the Ute Pass fault, near Colorado Springs, the road lies in pre-Cambrian granite, although at 73 miles (117.5 kilometers) there is abundant phonolite float which has washed down the hill from the upper part of Cow Mountain. The weathering of the coarse-grained reddish granite has given rise to many picturesque spires and domes. Good examples of these erosion forms may be seen at 80.2 miles (129.1 kilometers) in Cathedral Park, which lies ahead and slightly to the right. Beyond an old siding called Divide, at 90.5 miles (145.6 kilometers), is the first view of the plains. From this point to Colorado Springs the road winds steadily down the eastern front of the mountains, and the plains are frequently in sight.

At the former station of Duffields (93.6 miles, or 150.6 kilometers) is one of the most widespread views of the plains. Four-tenths of a mile (0.6 kilometers) farther on a dike or vein of fluorite about 15 feet (4.5 meters) wide is well exposed in an old cut. A few miles farther on the road skirts St. Peter's Dome, which is famous for the variety of pegmatite minerals found in its flank. At 97.6 miles (157.1 kilometers), on the northwest bank of a small creek, riebeckite and gem zircon may be collected from a pegmatite dike about 100 feet (30 meters) below the level of the road. Both astrophyllite and riebeckite are present in the pegmatite dike exposed in a road cut about half a mile (0.8 kilometer) beyond this locality. The road continues in granite to 106.5 miles (171.4 kilometers), where it enters the Ute Pass fault zone, and a small mass of Timpas limestone, of Niobrara age, can be seen in the road cut at the left.

At 107.3 miles (172.7 kilometers) there is a good exposure of overturned Timpas limestone and the underlying Carlile sandstone. The road turns sharply to the left, passes through the Dakota sandstone at 107.5 miles (173 kilometers), and crosses the Ute Pass fault into granite but swings back across the fault just before it reaches the tollgate at 107.9 miles (173.7 kilometers). Beyond the tollgate the Lytle sandstone and Glencairn shale members of the Purgatoire formation are well exposed. After passing through the Dakota sandstone ridge the road turns to the left and follows almost along the strike of the Graneros and Carlile shales and sandstone for 0.3 mile (0.5 kilometer) and then crosses through the Timpas limestone, which is here overturned. Pleistocene gravel then appears, and the road follows the top of a gravel terrace to 109.1 miles (175.6 kilometers), where a splendid view may be had of the hogbacks to the north and the Pleistocene terraces across the valley of Fountain Creek. The road turns sharply to the left and descends from the terrace and leads across Pierre shale through Colorado Springs.

113723—32——9

EXCURSION 3

Soon after leaving Florissant on the road to Divide and Colorado Springs the Florissant lake beds disappear, and the road remains in Pikes Peak granite for nearly 15 miles (24 kilometers). Divide is entered at 58.5 miles (94.1 kilometers). At 64.5 miles (103.8 kilometers) a sandstone dike, related to the Ute Pass fault, cuts the Pikes Peak granite. According to Cross (9) the dikes must be considered as injections of quicksand into fissures in the granite, but the source of the sand is unknown. At 64.8 miles (104.3 kilometers), where the road branches, the Ute Pass fault is concealed beneath soil, but within a short distance the micaceous red earthy sandstone and grits of the Pennsylvanian Fountain formation are visible at the left in a road cut. For the next 14 miles (22.5 kilometers) the road is in the Fountain formation, and erosion remnants crop out near the road in many places. At 78.5 miles (126.3 kilometers) the road crosses the Ute Pass fault, and granite is exposed in the road cut. At 79.5 miles (127.9 kilometers) a branch road turning sharply to the right is followed through the granite into the Fountain formation, which gives way to the Millsap (Mississippian) limestone at 80.8 miles (130 kilometers). At 90 miles (144.8 kilometers) the "fish farm" is reached. Here the Cambrian, Ordovician, and Mississippian rocks are well exposed, and good collections of their faunas can be easily obtained.

Excursion 3 retraces its way to the main road from Florissant to Colorado Springs, reaching it at 106.6 miles (171.5 kilometers). The contact between the Paleozoic sediments and the Pikes Peak granite is concealed beneath alluvium, and at 107.2 miles (172.5 kilometers) Pikes Peak granite crops out at the left. From this point to the mountain front the road remains in granite. At 116.5 miles (187.5 kilometers) the lower Paleozoic sediments, resting upon the granite, can be seen straight ahead. The reddish Manitou (Ordovician) limestone is easily distinguished from the underlying Sawatch quartzite (Cambrian) and the overlying Millsap limestone (Mississippian).

At 117.3 miles (188.8 kilometers) the contact of the granite and the Cambrian quartzite crosses the road. Three-tenths of a mile (0.5 kilometer) beyond this point the road enters Manitou. The Fountain formation can be seen on the right in several places. At 120.6 miles (194 kilometers) the contact of the Permian Lyons sandstone and the overlying Lykins formation (Triassic (?) and possibly Permian) is visible on the right. At 120.9 miles (194.5 kilometers) the Dakota hogback is at the right, across the stream. At 121.3 miles (195.2 kilometers) a hill of Pierre shale capped by Pleistocene gravel can be seen on

the left. At 123.5 miles (198.7 kilometers) the road crosses Monument Creek, and the business district of Colorado Springs lies just ahead.

The members of excursion 3 will have opportunity to study the geology of this region and to make faunal collections from Paleozoic and Mesozoic rocks. The stratigraphic sections and the general geology and structure of the eastern front of the range are reviewed briefly below.

FOOTHILL REGION OF NORTH-CENTRAL COLORADO

By Junius Henderson and T. S. Lovering

TOPOGRAPHY AND GEOMORPHOLOGY

The Great Plains, extending westward from the Missouri River, end abruptly at the base of the foothills in Colorado. Differential erosion of the sharply upturned sedimentary rocks, bordering the granitic complex of the Rocky Mountains, has produced a series of parallel north-south valleys and ridges. The outer ridge, or "first hogback," is formed by the Dakota sandstone, of basal Upper Cretaceous age, which has a tendency in places to split into two or even three ridges. The valley west of the Dakota ridge is occupied by the soft brick-red Lykins formation, flanked on the east by the Morrison formation and on the west by the Lyons sandstone. The second hogback, west of the valley, is formed by the Fountain (Pennsylvanian) and Lyons (Permian) formations. West of this ridge erosion along the contact of the Fountain and the harder underlying rocks has formed valleys, usually less pronounced than the Lykins valley. Where the older Paleozoic rocks are present they commonly form smooth steep slopes extending well up the mountain front. In most places the abrupt slopes of the mountains reflect the presence of hard pre-Cambrian rocks.

The easily eroded shales of the Upper Cretaceous Benton shale lie just east of the Dakota ridge. The overlying basal member of the Niobrara formation is a hard limestone, which in many places forms a low ridge at the east side of the Benton shale; a second hard zone at about the middle and a third at the top of the formation tend to form two other minor ridges. The streams from the mountains have carved many canyons through the foothill ridges, and farther east, in the Cretaceous shales at the edge of the plains, they have left many mesas and terraces bordering their channels. Most of these terraces and mesas are Pleistocene and are related to interglacial stages during which the streams were overloaded.

West of the foothill belt the pre-Cambrian complex forms a gradually rising plateau, dissected by deep canyons, extending nearly to the Continental Divide, where the crest of the Rocky Mountains rises steeply above it. Many of the peaks reach an altitude of over 13,500 feet (4,115 meters), and a few rise a little more than 14,000 feet (4,267 meters).

Several small glaciers occupy cirques at the top of the range, and the Arapahoe glacier, one of the most extensive, may be seen from the plains near Boulder.

The Front Range uplift is a regional monoclinal flexure but has many subordinate northwesterly échelon folds on its flanks. The series of échelon folds profoundly affects the topography of the foothills, causing strong offsets in the general north-south trend of the foothill line at various points, notably west of Longmont and west of Loveland. The general structure of the region is described on pages 21 and 23.

Northwesterly faults are numerous and commonly occur along the crests or troughs of northwestward-trending folds. Northeasterly faults of small throw are common in the sediments east and northeast of Boulder.

Small outcrops of igneous intrusive rocks occur along the foothills. Valmont Butte, on the plains east of Boulder, is a dolerite dike that cuts the Cretaceous formations and is exposed in a long, narrow ridge. The Table Mountains, at Golden, are capped by remnants of a flow of Eocene lava.

STRATIGRAPHY

A columnar section showing the general stratigraphy of the region is shown in the right-hand column of Plate 2. The mountain mass west of the foothills consists chiefly of pre-Cambrian granites, schists, and gneisses, cut by monzonite and granite porphyries of early Eocene age. Schistose pre-Cambrian quartzites occur at several places near the contact of the mountain complex and the younger upturned sedimentary rocks.

Cambrian.—The Sawatch quartzite, of Upper Cambrian age, rests unconformably upon the pre-Cambrian rock along the southern part of the Front Range. It has a maximum thickness of about 100 feet (30 meters), but in most places is much thinner than this, and in the region north of Castle Rock it is absent. It contains few fossils, but its lithology is characteristic and makes the formation easy to recognize.

Odovician.—The Manitou limestone, of Lower Ordovician age, unconformably overlies the Sawatch quartzite in the region near Colorado Springs, but it is absent north of Castle Rock. It ranges in thickness from 20 to 150 feet (6 to 46 meters) and

contains many fossils. It consists chiefly of red, pinkish, purple, and gray limestone but has a few thin layers of green shale. It is overlain by the Harding sandstone, of Middle Ordovician age, which ranges in thickness from 10 to 100 feet (3 to 30 meters) and consists chiefly of gray, pink, and white sandstone containing a few thin layers of greenish-gray shale. Many layers are very fossiliferous, and it contains the oldest known fish scales and fish plates. It is not found north of Colorado Springs and is best developed in the region near Canon City. The Harding sandstone is overlain by the Fremont limestone, of Upper Ordovician age, which is from 20 to 250 feet (6 to 76 meters) thick. It consists of gray and pinkish sandy dolomite and is moderately fossiliferous. It is not found north of Castle Rock.

Mississippian.—The Fremont limestone is unconformably overlain by a Mississippian limestone which is correlated with the Madison limestone of Wyoming. Its thickness ranges from a few feet to 100 feet (30 meters) but is commonly less than 80 feet (24 meters). It consists chiefly of dolomitic and cherty gray limestone but contains some red shale and sandstone in the upper part. It lies unconformably beneath Pennsylvanian rock in the Colorado Springs area and is not found north of Castle Rock.

Fossiliferous cherts found in later formations and in the loose gravel of the plains indicate that strata of Mississippian age were once widely distributed in the region. Their destruction before the deposition of the post-Mississippian formations seems to have been complete in the northern part of the Front Range, as no remnant of such beds has been found in the well-exposed sections along the foothills. A thick bed of Mississippian chert pebbles rests on granite at the base of the Fountain formation west of Owl Canyon, northwest of Fort Collins.

Pennsylvanian.—The Glen Eyrie shale member of the Fountain formation, of lower Pennsylvanian age, occurs near Colorado Springs and includes about 90 feet (27 meters) of gray sandstone and black shale, which contain abundant lower Pennsylvanian plants at many places. It is conformably overlain by the rest of the Fountain formation, which consists essentially of reddish arkose, sandstone, coarse conglomerate, and sandy shale. The individual beds are lenticular, and cross-bedding is very common. The Fountain formation ranges in thickness from 500 to 4,500 feet (152 to 1,372 meters).

In the northern part of the area the Ingleside formation (Pennsylvanian) rests upon the Fountain formation. It is a series of alternating thick beds of limestone and sandstone, ranging from 100 to 125 feet (30 to 38 meters) in thickness in the northern part of the State, well exposed in Owl Canyon

and northward, but thinning toward the south and finally disappearing north of the St. Vrain River. The limestones are fossiliferous.

Permian and Triassic.—The Lyons sandstone of Permian age, 75 to 250 feet (23 to 76 meters) thick, rests upon the Fountain formation south of the Boulder-Lyons district and upon the Ingleside formation in the northern area. It consists of fine-grained cross-bedded quartzose sandstone, with siliceous cement and a pinkish color due to iron oxide. At Boulder it forms the east flank of the second hogback. It has been extensively quarried at many places for building, because of its fine grain and extreme hardness. At the north, as well shown at Owl Canyon, this sandstone is underlain by soft reddish beds, similar to the overlying Lykins, suggesting that it might there be merely a local phase of the Lykins, though farther south this does not appear to be true.

The Lykins formation rests upon the Lyons sandstone and is from 200 to 600 feet (61 to 183 meters) thick. Because of its softness and its position between hard, resistant formations, the Lykins forms an almost continuous north-south valley between the first and second hogbacks, except where interrupted by the gulches cut by mountain streams flowing across the foothills to the plains. It consists of soft sandstone and sandy shale, with some calcareous bands and one persistent bed of gypsum. It is largely of rich brown and brick-red colors. The "crinkled limestone" member in the lower part is crumpled and brecciated, although no such structure is found in the overlying and underlying members of the formation. About 200 feet (61 meters) above the base of the Lykins northeast of Owl Canyon were collected *Bellerophon crassus* Meek and Worthen and *Myalina subquadrata* Sumard, which are found in both Pennsylvanian and Permian rocks. These have been found also in the Ingleside formation. A stratum 300 feet (91 meters) above the base of the Lykins has yielded *Myalina wyomingensis* (Lea), *M. perattenuata* Meek and Hayden, *Alula squamulifera* Girty, *A. gilberti* (White)?, and *Murchisonia buttersi* Girty, suggesting a Permian age. The age of the upper 100 to 400 feet (30 to 122 meters) of the Lykins is not known, and Triassic and possibly Jurassic strata may be represented in it.

Jurassic.—Certain sandy beds above the Lykins and below the Morrison in northern Colorado are considered a southern extension of the marine Jurassic Sundance formation, which is well developed in Wyoming.

Cretaceous (*?*).—The Morrison formation, of fresh-water origin, whose age has been long in dispute, lies between the Lykins and the overlying Purgatoire formation in the Colorado Springs

region, between the Lykins and the Dakota formation in the Boulder area, and between the Sundance and Dakota formations in the Owl Canyon district. It is from 200 to 300 feet (61 to 91 meters) thick and consists of sandstone, variegated shale, and some limestone. In Wyoming and in the Morrison and Canon City districts of Colorado this formation has yielded dinosaurian remains and shells of fresh-water mollusks.

Lower Cretaceous.—Marine sediments of upper Comanche (Washita) age are well developed in southeastern Colorado, where they are called the Purgatoire formation, but north of Colorado Springs, if present, they have not been separated from the overlying Dakota formation. The Purgatoire formation is divided into two members—the light-colored basal Lytle sandstone, about 150 feet (46 meters) thick, and the overlying dark-colored Glencairn shale, from 50 to 100 feet (15 to 30 meters) thick. The Purgatoire formation is separated from the overlying and underlying formations by slight unconformities.

Upper Cretaceous.—In the northern part of the Front Range region the Dakota formation (basal Upper Cretaceous), which forms the first hogback of the foothills, consists of a thick basal conglomerate, a middle zone of shale and weak sandstone, and an upper sandstone. Near Colorado Springs it consists of 100 feet (30 meters) of light-colored quartz sandstone. At Boulder it forms a single ridge, but farther north, in some places, it splits into two or even three ridges.

Marine fossils occasionally found in beds below the upper sandstone suggest that all but the upper sandstone is of Comanche (Lower Cretaceous) age. The age of the upper sandstone is in doubt, but it contains leaves of land plants and may be Upper Cretaceous. Some geologists have considered it a portion of the Benton shale, but the line of demarcation between the sandstone and the overlying Benton shale is so abrupt and clear-cut that it seems better to consider them separate formations. The upper sandstone is about 50 to 100 feet (15 to 30 meters) thick, and north of Colorado Springs the total thickness of the formation is about 200 feet (61 meters).

The deposits of Benton age (Upper Cretaceous) occupy a gentle slope eastward from the base of the Dakota foothill ridge or a broad, shallow valley between the Dakota and the deposits of Niobrara age. They are conformable with the overlying and underlying formations. In the region south of Colorado Springs these deposits are divided into three formations—at the base the sandy Graneros shale, about 200 feet (61 meters) thick; in the middle the Greenhorn limestone, about 50 feet (15 meters) thick; and at the top the Carlile shale, about 100 feet (30 meters) thick. Farther north the three formations can not be distin-

guished from one another, and the whole unit is called Benton shale. In the northern part of the Front Range region the Benton consists chiefly of black shale, commonly with a strong bituminous odor, but in the upper part it contains intercalated limestone bands several inches in thickness which yield marine fossils, and at the top it carries the Codell sandstone member, called "Nio-Benton sandstone" by petroleum geologists. The most common fossil in the limestone bands is *Inoceramus labiatus* Schlotheim. Toward the base of the formation fish scales similar to those of the Mowry shale of Wyoming are found.

South of Colorado Springs the deposits of Niobrara age are divided into the basal Timpas limestone, about 200 feet (61 meters) thick, and the overlying Apishapa shale, about 400 feet (122 meters) thick, but farther north the Timpas and Apishapa are not recognized. The hard basal limestone of the Niobrara contains large marine clams, *Inoceramus deformis* Meek, to which *Ostrea congesta* Conrad is usually attached. These shells occur throughout the formation. Above the basal part are thin-bedded limestones and shales, topped by "paper" shales, with another ridge-making limestone at the top.

The Pierre shale, conformably overlying the Niobrara deposits, covers a large area east of the foothills, and its thickness ranges from 4,000 to 8,000 feet (1,219 to 2,438 meters). Some of the clays are used extensively in brickmaking. The lower part, which is almost entirely barren of fossils, is black clay shale. Above this shale the formation consists of four or five sandstones separated by shales. Portions of the sandstones are highly fossiliferous. The upper part of the formation is much more sandy than the lower part and grades into the overlying Fox Hills sandstone.

The Fox Hills sandstone is marine in northern Colorado, but south of Colorado Springs it is in part of fresh and brackish water origin. It consists of alternating shale and thin sandstone beds, capped by a massive sandstone called the Milliken sandstone member. Most of its outcrops lie several miles out from the foothills. Fossils are scattered throughout the formation and are common locally in certain strata. Its contact with the underlying Pierre is gradational in most places, and a definite lower limit is difficult to assign. It is approximately 600 feet (183 meters) thick.

The Laramie formation is the uppermost division of the Cretaceous in the Denver Basin region and is from 200 to 600 feet (61 to 183 meters) thick. It is of fresh and brackish water origin and marks the retreat of the Cretaceous sea. It yields all the marketable coal of northeastern Colorado. Many fossil leaves have been collected from it, but in this area no fossil ani-

mal remains are found except *Ostrea glabra* Meek and Hayden, a brackish-water form. The Crow Creek region, northeast of Greeley, was made famous many years ago by White, who described a large fauna of fresh and brackish water mollusk shells from the Crow Creek Laramie, a fauna notable for the large number of species and individuals of *Corbicula*.

Tertiary (*Eocene*).—In the region from Colorado Springs to Denver much of the surface is covered by the Dawson arkose, whose basal portion grades northward into the Denver formation. These formations are of early Eocene age and rest unconformably upon the Upper Cretaceous rocks. They consist chiefly of sandstone and grit near the mountains, but thick shale members are common 15 to 20 miles (24 to 32 kilometers) east of the mountain front. Near the lower part of the formations workable coal seams have been found east of Denver. The Denver formation is notable for the andesitic character of its grit and sandstone and for the presence of interbedded basalt lavas near Golden. About 20 miles (32 kilometers) south of Denver, where the Denver formation merges with the Dawson arkose, the andesitic material gives way to pre-Cambrian débris which is characteristic of the Dawson arkose. The maximum thickness of these Eocene sediments is approximately 2,000 feet (610 meters).

The Dawson arkose is unconformably overlain by the Castle Rock conglomerate, of Oligocene age. This formation is only a few hundred feet thick and caps the mesas northwest and southeast of Castle Rock. The Tertiary formations that once covered the region bordering the northern part of the Front Range have been destroyed by the erosion of the South Platte River and its tributaries.

In the northern and northeastern parts of the State, where the formations still exist, the Oligocene Chadron and Brule formations are overlain by the Miocene Arikaree formation, which consists of interbedded shale, clay, and sand, and by the Ogalalla formation (late Miocene and Pliocene). A rich fauna of fossil mammals has been found in the eastern part of the State and in Kansas and Nebraska near the Colorado boundary.

Pleistocene.—Pleistocene gravel forms extensive terraces bordering the mountain front. In many of these deposits the teeth of mammoths have been found.

COLORADO SPRINGS TO CANON CITY

From 4.3 to 8 miles (6.9 to 12.9 kilometers) beyond Colorado Springs many low conical mounds and hills may be seen rising from the plain at the left. These are caused by differential erosion of columnar limestone reefs in the Pierre shale and are

known as Tepee Buttes. The Pierre shale and the uneven erosional unconformity between it and the overlying Pleistocene terrace gravel are well exposed in road cuts along the winding portion of the road from 9.1 to 12 miles (14.6 to 19.3 kilometers). From 12 to 12.6 miles (19.3 to 20.3 kilometers) the road runs very close to the pre-Cambrian granite, which is brought against the Pierre shale here by the Ute Pass fault. The hogback ahead is held up by Dakota sandstone, which runs northeastward into the Ute Pass fault at this place. At 13.7 miles (22 kilometers) the road swings across the strike of the sediments, and a fairly good section is well exposed in the next 1½ miles (2.4 kilometers), beginning with the Apishapa shale and continuing with the Timpas limestone at 14 to 14.3 miles (22.5 to 23 kilometers), the Greenhorn limestone at 14.4 miles (23.2 kilometers), and the Dakota hogback at 14.6 miles (23.5 kilometers), with the Morrison formation and Lykins formation at the left. At 14.8 miles (23.8 kilometers) the reddish sandstone forming a low hogback at the left is the Lyons sandstone, which overlies the Fountain formation. It is about 85 feet (26 meters) thick at this place. The road swings to the left and runs nearly parallel to the strike of the formations and for many miles winds through the Lyons, Fountain, Lykins, or Morrison, which are easily identified by their relation to the Dakota and Lyons hogbacks or escarpments.

A good exposure of the Morrison and the Lykins can be seen on the hill ahead at 24.8 and 25.2 miles (39.9 and 40.6 kilometers). From 27.2 to 31.7 miles (43.8 to 51 kilometers) the road climbs slowly through Morrison and Purgatoire formations to the top of the Dakota. Here there is a good view of the Wet Mountains ahead and to the left and of the Front Range back and to the right. From 33.8 to 34.3 miles (54.4 to 55.2 kilometers) Graneros shale is exposed near the road in the valley of Beaver Creek. At 34.6 miles (55.7 kilometers), partly up the hill leading out of the Beaver Creek Valley, Greenhorn shale capped by Carlile sandstone and Timpas limestone may be seen a short distance to the right of the road. From 46.2 to 47.2 miles (74.4 to 76 kilometers) there are several exposures of Pierre shale in the road cuts. At 47.9 miles (77.1 kilometers) is the bridge over Oil Creek. The oil seep that led to the discovery of the Florence oil fields was found at the head of this creek before 1862. At 50.2 miles (80.8 kilometers) Canon City is reached, and at 51.2 miles (82.4 kilometers) the Strathmore Hotel.

At 51.6 miles (83 kilometers) the State penitentiary is on the right. At 52 miles (83.7 kilometers) the excursion will leave the main road, turning left to the St. John's quarry at 52.6 miles (84.7 kilometers), where collections of fish scales, lingulas,

cephalopods, pelecypods, and gastropods can be made from the Ordovician sandstones and shales of the Harding formation. The main road follows the western base of the Dakota, and at 54 miles (86.9 kilometers) the unconformable contact of the Morrison formation and the Fountain formation is well exposed. Both the Lykins and the Lyons formations are overlapped by the Morrison a few miles east of Canon City. At 55.8 miles (89.8 kilometers) the road turns sharply to the right and climbs to the top of the Dakota hogback, cutting across the Morrison and the Purgatoire formation. At 57.6 miles (92.7 kilometers) the road crosses to the Dakota. Here a good view may be had of the general region, and much of its geology can be interpreted from the topographic expression of the various formations. At 58.1 miles (93.5 kilometers) the road turns sharply to the left, descending through the Graneros shale until at 58.4 miles (94 kilometers) it turns to the right through the Greenhorn limestone the Carlile shale, and the Timpas limestone. The excursion returns to Colorado Springs, by the same route.

DENVER TO NEDERLAND AND CENTRAL CITY

INTRODUCTION

By T. S. Lovering

The general geology of the eastern part of the Front Range has been described on pages 21 and 23. Most of the geologic section can be seen on the trip from Denver to Morrison, the type locality of the Morrison formation. (See pl. 14.) Near Golden, as already noted, much of the section between the Denver and Fountain formations is cut out by north-south faults that are nearly parallel to the bedding of the sediments and extend several miles north and south of the town. A few miles north of Golden the route of the excursion crosses the well-developed Pleistocene gravel terraces that border Clear Creek, Ralston Creek, and Coal Creek. It is believed that there were five different stages of terrace formation. The oldest or first terrace, the third terracc, and the fifth terrace are more extensive than the others.

The quartz schist, quartzite, and quartz conglomerate exposed in Coal Creek Canyon are lenticular members of the Idaho Springs formation, which in most places in the Front Range, is composed chiefly of quartz-biotite schist and quartz-biotite-sillimanite schist. This formation consists of metamorphosed sediments and is probably the oldest rock in Colorado. Granites of many types are abundant in the pre-Cambrian complex, and several will be seen by this excursion between Nederland and

Idaho Springs. Early Eocene porphyries are also common in the pre-Cambrian terrane. Most of them belong to the monzonite, quartz monzonite, or granite family, but a few alkali-rich rocks, such as bostonite and aegirite syenite, are present. Both dikes and stocks are common, but most of the stocks lie on the western or northwestern side of the mineralized belt.

GEOLOGY OF THE GOLDEN AREA

By F. M. Van Tuyl

The Golden area (pl. 15) is of unusual interest to the geologist in that it exhibits a large variety of typical physiographic and geologic features characteristic of the eastern boundary of the Front Range of Colorado and of the foothills. In general the Front Range consists of a series of high peaks along the Continental Divide, some of which have shoulders at an altitude of about 12,500 feet, or 3,810 meters (Flattop peneplain), some distance above the general level of the imperfectly developed eastward and westward sloping erosion surfaces that constitute the Rocky Mountain peneplain. Remnants of this lower peneplain appear on and near Lookout Mountain, just west of Golden, at an altitude of about 7,600 feet (2,316 meters).

The foothill belt includes a relatively narrow strip that forms a transition zone from the mountainous area of the Front Range to the monotonously low rolling surface of the Great Plains. In the Golden area it consists of alternating hogbacks and valleys, lava-capped mesas, and residual hills locally modified by terrace gravel.

GEOMORPHOLOGY

The relief features of the area are closely related to the Foothill monocline, which is here somewhat complicated by reverse faulting. At least three cycles of erosion are involved in their geomorphic development.

As a result of the differential erosion of tilted beds of unequal hardness during the late stages of development, sinuous hogback ridges were formed from the more resistant strata, while longitudinal valleys were developed on the softer deposits. The most prominent hogback is that formed by the Dakota sandstone. Less striking hogbacks appear locally over certain hard layers in the lower part of the Fountain formation, the Lyons sandstone, a limestone member of the Lykins formation, the limestone forming the lower part of the Niobrara formation, and the sandstones in the basal part of the Laramie formation. In the immediate vicinity of Golden the disappearance of several formations, ranging from upper Fountain to Fox Hills,

as a result of reverse faulting, accounts for the absence of pronounced hogback ridges.

The lava-capped mesas to the east constituting North Table Mountain and South Table Mountain, as well as Green Mountain, to the south, are erosion remnants developed in nearly horizontal Tertiary continental deposits in the area of rapid flattening of the faulted monocline.

The abrupt rise of the Rocky Mountain front along the west boundary of the foothills is ascribed to the more rapid erosion of the less resistant sedimentary rocks that followed the uplift of the Rocky Mountain peneplain in late Tertiary time.

A well-defined shoulder at an altitude of about 6,500 feet (1,981 meters) on the east flank of Mount Morrison, 6 miles (9.6 kilometers) south of Golden, appears to represent a remnant of a lower and younger peneplain than the Rocky Mountain surface. This has been designated the Mount Morrison peneplain by the writer. Numerous wind gaps in the Dakota hogback, such as the one east of the mouth of Mount Vernon Canyon, were undoubtedly formed through the capture of eastward-flowing streams by longitudinal streams after the uplift of this peneplain. The present surfaces of North and South Table Mountains are believed to represent remnants of this plain of denudation. In the Arkansas Valley of southern Colorado a similar erosion surface is partly buried by gravel of probable Pliocene age.

The uplift of the Mount Morrison peneplain prior to the end of the Pliocene epoch introduced a new cycle of erosion in the plains and foothills. There is some evidence that locally the old-age stage of this cycle was reached prior to the uplift that caused the early Pleistocene glaciation. Thus in the vicinity of Boulder there are remnants of a gravel-strewn plain at an altitude of about 5,500 feet (1,676 meters).

Along the valleys of Clear Creek and Ralston Creek several well-defined terraces appear in the Pleistocene gravel. These slope both streamward and downstream. In the higher terraces the gravel rests upon uneven rock benches formed by the truncation of strata of unequal hardness.

The early Pleistocene gravel deposits were spread out over the interstream areas, but the late Pleistocene deposits were largely confined to valleys developed in middle Pleistocene time. This implies an old-age stage of stream development prior to glaciation.

STRATIGRAPHY

The accompanying stratigraphic table gives briefly the character and thickness of the individual formations of this area.

Geologic formations in Golden area[1]

Age	Formation	Character	Thickness	
			Feet	Meters
Recent.		Gravel along streams.		
Pleistocene.		Alluvium and terrace gravel.		
		—Unconformity—		
Eocene.	Denver formation.	Interbedded sandstone, conglomerate boulder beds, and clay; chiefly andesitic débris.	950	290
	Arapahoe formation.	Sandstone, conglomerate, and clay.	800	244
		—Disconformity—		
Upper Cretaceous.	Laramie formation.	Sandstone, shale, clay, and lignite seams.	600 ±	183 ±
	Fox Hills sandstone.	Gray sandy shale and shaly sandstone, weathering buff.	800 ±	244 ±
	Pierre shale.	Lead-gray shale, sandy near the top. Thin lenticular limestone and sandstone layers.	4,500 ±	1,372 ±
	Niobrara formation.	Gray limestone overlain by gray calcareous shale.	450	137
	Benton shale.	Dark lead-colored carbonaceous shale.	400	122
	Dakota sandstone.	Hard, massive sandstones with thin seams of clay.	75	23
		Conglomerate at base; hard massive sandstone, sandy shale, and fire clay above.	190	58
		—Disconformity—		

Lower Cretaceous (?) (may be Jurassic).	Morrison formation.	Variegated green-gray and maroon shale with lenticular limestone and sandstone.	180	55
		—Disconformity—		
Triassic (?).	Lykins formation.	Brick-red sandy shale and sandstone with thin limestone and gypsum beds in lower portion.	600	183
----------?----------				
Permian.	Lyons sandstone.	Massive cross-bedded cream-white sandstone.	200	61
Pennsylvanian.	Fountain formation.	Red arkosic sandstone and conglomerate with interbedded red shale.	1,200+	366+
		—Unconformity—		
Archean.		Gneiss and schist with granite and pegmatite intrusions.		

STRUCTURE

The Front Range has been deeply dissected as a result of repeated uplifts. Remnants of at least three erosion surfaces are preserved. Two of these are within the range, and the third forms shelves and other remnants along its eastern margin. Although there is evidence that the uplift of this great anticline began in pre-Laramie time, it has been definitely established that the movement attained its maximum development in post-Denver time, inasmuch as the Denver formation is involved in the intense deformation of the foothill belt.

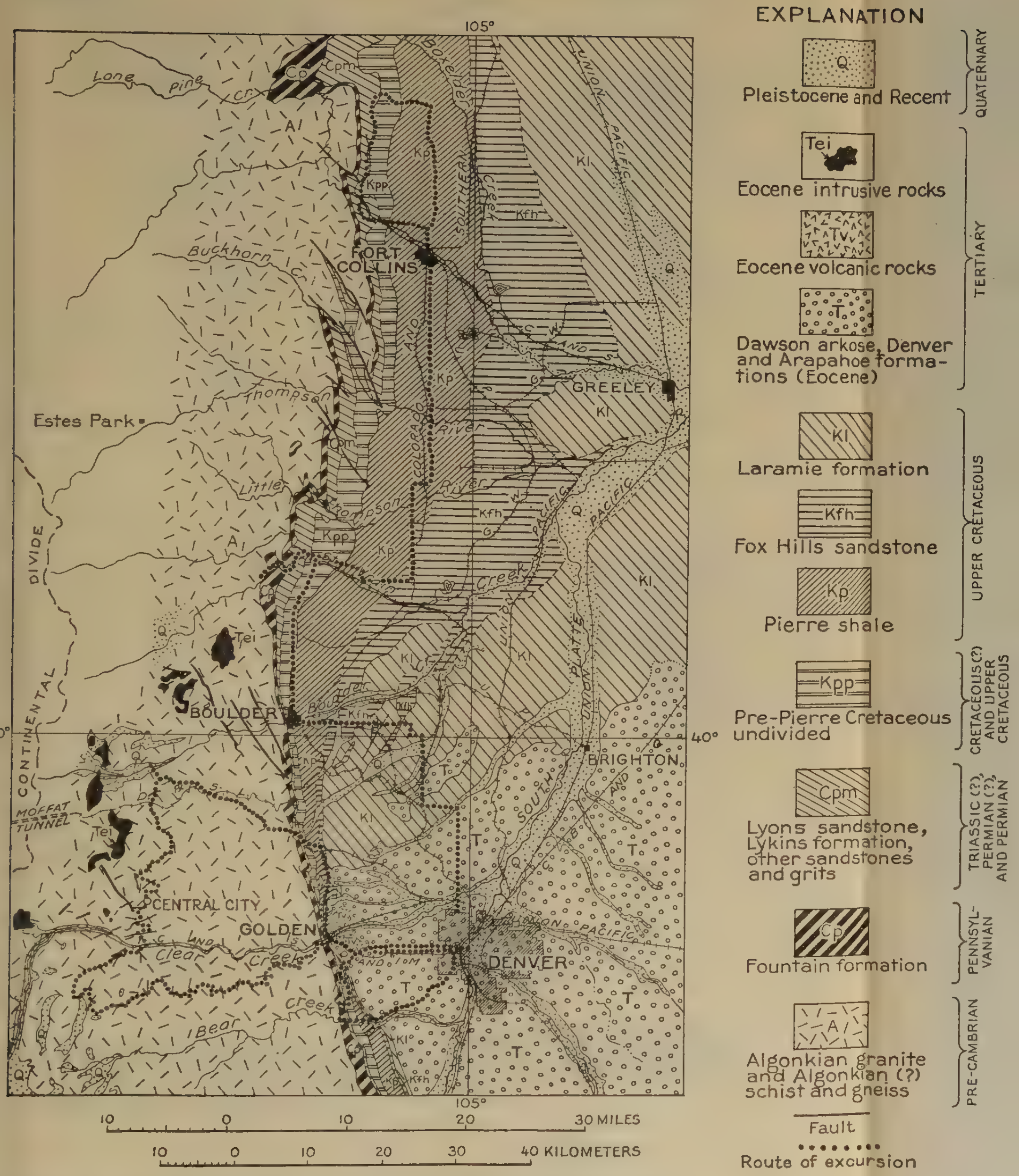
In the Golden area this post-Denver uplift, which is correlated with the Laramide revolution, was accompanied by reverse faulting, which resulted in a displacement of more than 1 mile (1.6 kilometers). The geologic map of the area does not reveal evidence of important eastward bulging of the crystalline rocks in the area of maximum displacement along the fault. Conversely, there is a westward bulging of the late Cretaceous and early Eocene deposits lying east of the fault, including particularly the Fox Hills, Laramie, Arapahoe, and Denver formations. This situation leads the writer to believe that westward underthrusting of the younger sedimentary rocks has probably been more extensive than the eastward overthrusting of the pre-Cambrian crystalline rocks and late Paleozoic sedimentary rocks. (See cross section, pl. 15.) Ziegler (39) first recognized reverse faulting in the foothills.

A considerable degree of brecciation occurs along the fault. The brecciated zone is in places as much as 100 feet (30 meters) in width. Wedges of variable width of formations far out of their normal stratigraphic position occur along the fault where it is compound in character, as at the point where it crosses Gold Run. There are also marked discordances in strike and dip on the two sides of the fault. In the area represented by the accompanying geologic map (pl. 15) the formations west of the fault zone show the normal easterly dip, averaging between 45° and 50°, but those immediately east of the zone are everywhere overturned. Owing to the highly disturbed condition of the fault zone it is not possible to determine its dip.

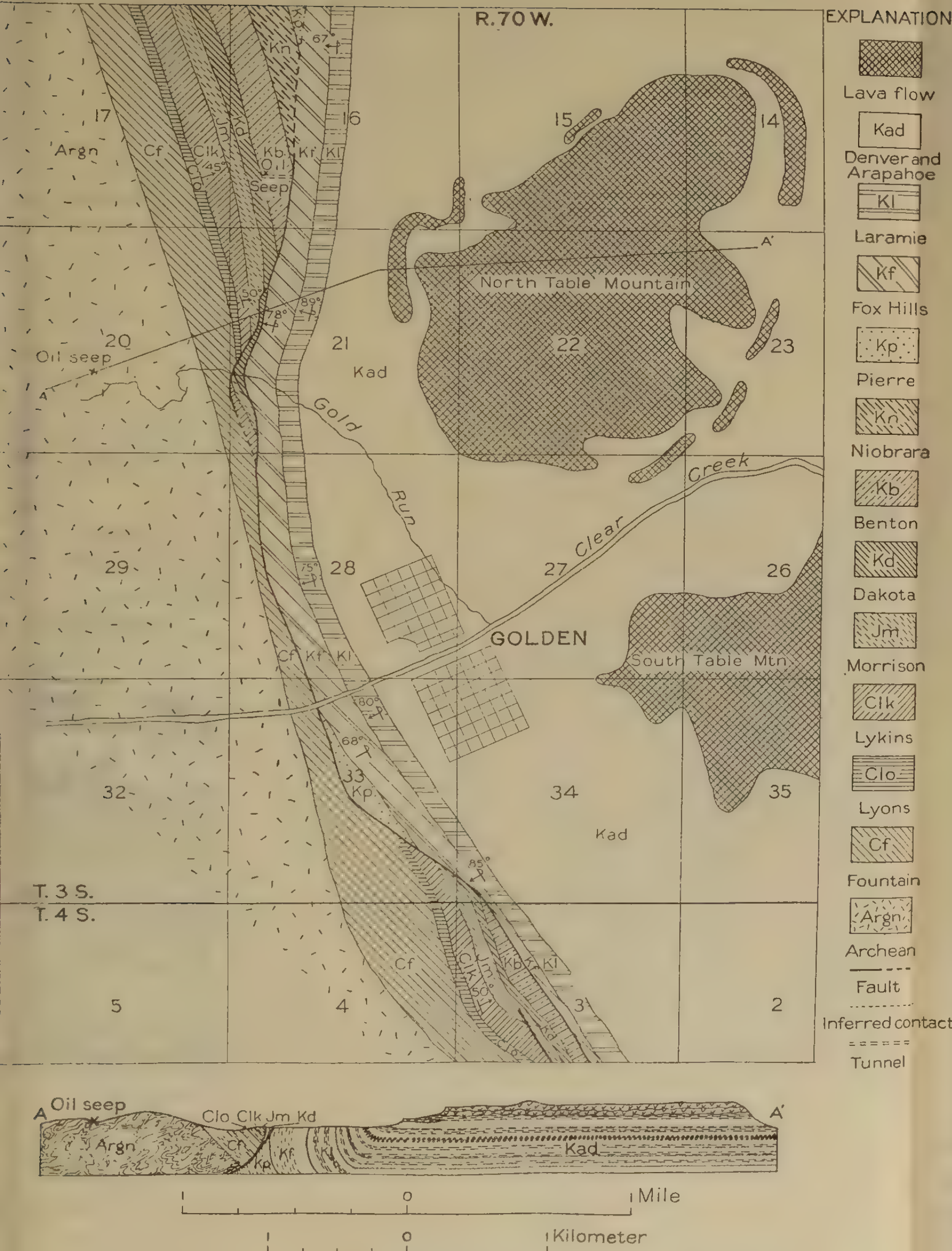
ROAD LOG

By C. E. Dobbin, T. S. Lovering, and F. M. Van Tuyl

The road leads north out of Golden on the Denver formation but is not far west of the Fountain formation, which has been faulted against much higher beds by a north-south fault. At 2.2 miles (3.5 kilometers) there is a good view of Lookout Mountain and the valley of Clear Creek to the south. A remnant of

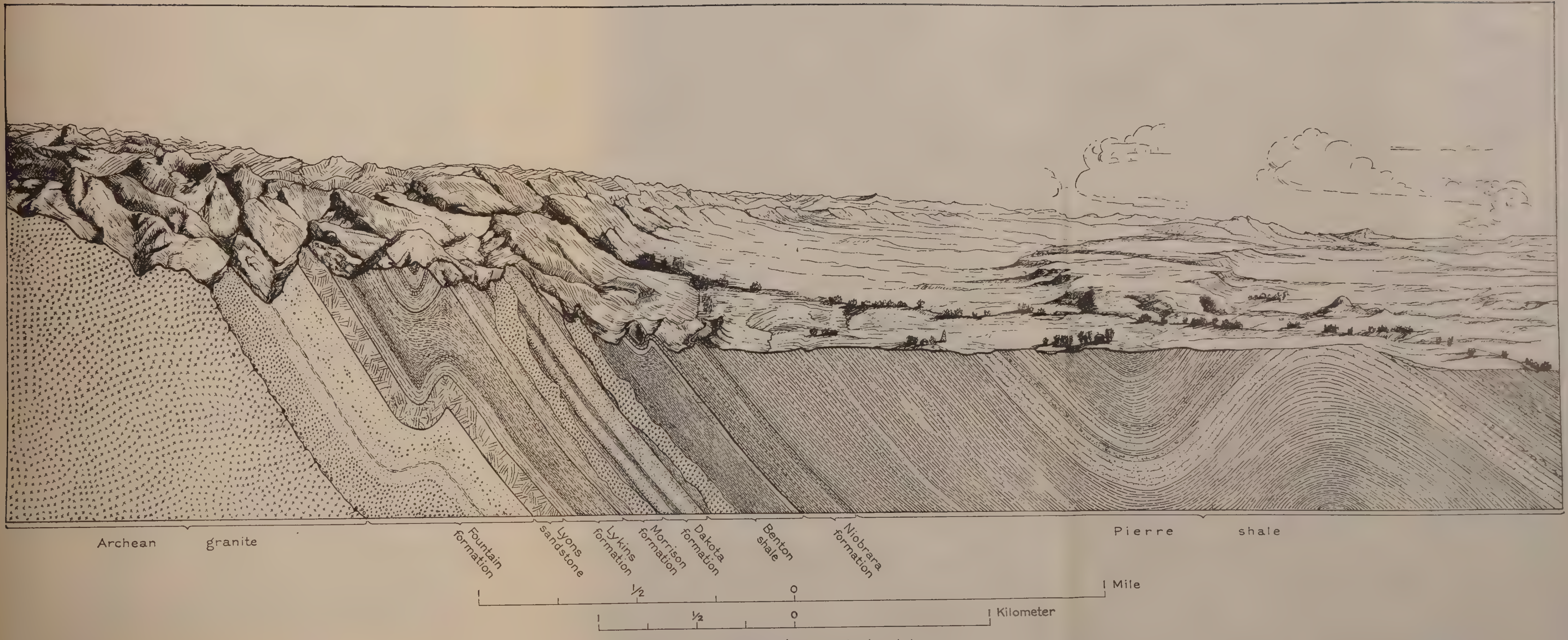


GEOLOGIC MAP SHOWING ROUTE OF EXCURSIONS FROM DENVER AND FORT COLLINS



GEOLOGIC MAP AND SECTION OF GOLDEN AREA

By F. M. Van Tuyl and R. L. McLaren. The oil seep shown in the section probably travels along the schistosity from the sedimentary rocks. The source of the lava is a vent in the sedimentary rocks, evidence of which is found 1,000 feet from the line of the section.



DIAGRAMMATIC SECTION 6 MILES NORTH OF BOULDER

By R. D. Sample and J. W. Low, University of Colorado. Direction of section S. 75° E.

an early Pleistocene or late Pliocene surface is conspicuous well up on Lookout Mountain, through which Clear Creek has cut a deep canyon. To the east three interbedded lava flows in the Denver formation crop out prominently on North Table Mountain. Directly ahead (north) high terraces of Pleistocene age are well exposed. At 4.8 miles (7.7 kilometers) the road swings over the crest of a hill slightly below the highest gravel-covered terrace and descends over four terraces to the valley of Ralston Creek. Near Coal Creek the road is chiefly on terrace gravel, although vertical Laramie sandstones truncated on a level with the high Pleistocene terrace are well exposed from 8.5 to 9 miles (13.6 to 14.4 kilometers). At 12.3 miles (19.8 kilometers) the road enters Coal Creek Canyon, and from this point to 16 miles (25.7 kilometers) it is chiefly in pre-Cambrian quartz schist and quartzite. At 21.7 miles (34.9 kilometers) there is a good view of the Continental Divide, which rises well above the late Tertiary Rocky Mountain peneplain. From 16 to 27.9 miles (25.7 to 44.9 kilometers) the road is in granite, and thence to Nederland at 32.1 miles (51.7 kilometers) the road is chiefly in the Idaho Springs formation, the earliest pre-Cambrian rock of the Front Range. At 31 miles (49.9 kilometers) there is a good view of lateral moraines of the late Pleistocene Wisconsin ice sheet, directly ahead, about 1 mile (1.6 kilometers) away. Boulders of the early Pleistocene glacial drift are abundant on the hill to the right of the road at this place.

After a brief visit to some of the tungsten mines near Nederland (see p. 140) the excursion turns south to Central City. Although the road between the two towns is chiefly in schist, many small bodies of granite are passed. At 18.3 miles (29.4 kilometers) from Nederland the crest of a sharp anticline in the Idaho Springs formation is well exposed to the left of the road.

Central City is reached 20 miles (32 kilometers) from Nederland. Much of the rock in the vicinity of Central City and Blackhawk is gneissic granite and the injection gneiss of the Idaho Springs formation. At 24 miles (36.8 kilometers) the road crosses a divide and turns left down the side of Virginia Canyon toward Idaho Springs. From this point to Idaho Springs (30.1 miles, or 48.4 kilometers) the road is in schist.

About 5 miles (8 kilometers) south of Idaho Springs the road leaves the Idaho Springs formation and enters the border facies of the Pikes Peak granite batholith. Thence to a point about 3 miles (4.8 kilometers) southeast of Echo Lake it crosses the Pikes Peak granite, which is well exposed in many places.

At 14.7 miles (23.7 kilometers) the route reaches Echo Lake. After leaving the main mass of Pikes Peak granite the road is

almost entirely in the Idaho Springs formation to the mountain front near Golden, although it crosses a few small masses of the Pikes Peak granite and the later Silver Plume granite. At 5.7 miles (9.2 kilometers) from Echo Lake there is a good view of the Rocky Mountain peneplain at the left (north). At 30.7 miles (49.4 kilometers) from Echo Lake, on the east edge of Lookout Mountain, there is a good view of Green Mountain and the plains to the east. The terraces north of Golden that were crossed earlier in the day are conspicuous, and their relations to one another and to the mountain front are well shown. The road after winding down the front of Lookout Mountain turns sharply to the north across the Fountain formation but within a short distance enters the faulted Laramie, which is marked by a line of pits where the fire-clay strata have been excavated for use in the pottery plants at Golden. From this place to Denver the road lies in the Denver formation.

ORE DEPOSITS OF NEDERLAND, CENTRAL CITY, AND IDAHO SPRINGS

By T. S. Lovering

The ore deposits of Nederland occur in veins trending east to northeast and are chiefly in pre-Cambrian pegmatite, aplite, and granite. The veins follow faults of comparatively small throw along which repeated movement has taken place. The deposits are fissure fillings and consist essentially of chalcedonic quartz and ferberite (ferrous tungstate) containing less than 1 per cent of manganese. In the western part of the tungsten district much of the ferberite is coarsely crystalline, but in the veins farther east it is much finer grained. The ore occurs in masses, as brecciated fragments cemented by later opaline or chalcedonic quartz, or as a matrix cementing fragments of finely crystalline vein quartz. In many places late barite is associated with the ore, and throughout the district fine-grained white kaolin occurs in vuggy openings in the ferberite itself. The wall rocks of the principal veins are strongly kaolinized and slightly sericitized close to the veins, but this alteration occurred prior to ore deposition. The district has been one of the most productive tungsten districts in the United States.

Although no gold or silver is present in the ferberite veins at Nederland, gold telluride veins occur at Eldora, about 3 miles (4.8 kilometers) southwest of Nederland. Several pyritic gold veins and a few pyritic galena-sphalerite veins are found between Eldora and Central City. The Idaho Springs-Central City district has been one of the most productive in the Front Range and is about 12 miles (19 kilometers) due south of Nederland.

Its chief deposits are pyritic copper-gold veins and galena and sphalerite gold-silver veins. The ores of this district show a rude zonal arrangement. Around the central area of gold-bearing pyritic veins between Blackhawk and Russell Gulch (2¾ by 1¾ miles, or 4.4 by 2.8 kilometers) there is a belt of gold-silver veins characterized by abundant sphalerite and galena, minerals rarely found in the inner zone. The second zone is in turn nearly surrounded by one in which silver veins are abundant. Some of the gold veins have been worked to great depths, and the California-Hidden Treasure has been mined 2,200 feet (670 meters) below the surface.

In Russell Gulch, just south of the area of pyritic gold veins, many closely related gold veins carrying enargite and fluorite are found. Another variant of the pyritic gold veins is found just north of Russell Gulch, where gold-bearing uraninite veins are common. The enargite-fluorite gold-pyrite veins lie between the pyritic gold area and a region in which galena-sphalerite ores are abundant. As a general rule the sphalerite and galena increase in all directions away from the central pyritic area, and the silver generally increases with the proportion of sphalerite in the ore. In the pyritic gold veins the gold increases with the chalcopyrite. The changes in depth are very similar to the lateral changes; galena-sphalerite veins commonly become pyritic in depth and in many places contain more gold below the dominantly galena-sphalerite ore. A few veins of high-grade gold telluride have been found in the outer zone of mineralization. The ore occurs chiefly as simple fissure fillings, and most of the ore bodies are related to features that produced open spaces in the premineral fault at the time of mineralization. Vein intersections, or "crossings," as they are locally known; the steepening of a vein in a premineral normal fault or the flattening of one in a reverse fault; steplike changes in the course of a vein; strong walls, such as granite gneiss; walls of dissimilar rocks, such as schist and porphyry; and veins transverse to the metamorphic structure of the country rock are all regarded as favoring the formation of ore deposits. Sericitization is the dominant type of wall-rock alteration. The production from 1859 through 1930 of Gilpin County, the bulk of which came from the south end of the county, has been (in terms of recovered metals) 4,231,000 ounces (131,598,823 grams) of gold, 10,666,000 ounces (331,749,717 grams) of silver, 25,668,000 pounds (11,642,759 kilograms) of copper, 36,477,000 pounds (16,545,714 kilograms) of lead, and 398,000 pounds (180,530 kilograms) of zinc. The production of Clear Creek County, which includes the mines near Idaho Springs, Lamartine, Lawson, Dumont, Alice, Empire, Georgetown, and Silver

Plume, from 1859 through 1930 has been (in terms of recovered metals) 1,151,000 ounces (35,800,105 grams) of gold, 58,720,000 ounces (1,826,396,357 grams) of silver, 12,058,000 pounds (5,469,389 kilograms) of copper, 181,048,000 pounds (82,121,763 kilograms) of lead, and 31,509,000 pounds (14,292,268 kilograms) of zinc.[13]

BIBLIOGRAPHY, EXCURSIONS 2 AND 3

1. Bartram, J. G., Possibilities in the Julesburg Basin: Oil and Gas Jour., vol. 28, pp. 89, 90, 94, 98, Jan. 23, 1930. Maps and a brief discussion of the stratigraphy and structure of this region, northeastern Colorado.

2. Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colorado: U. S. Geol. Survey Prof. Paper 94, 1917. General geology of region and detailed description of many mines. Includes Central City and Idaho Springs mining district.

3. Behre, C. H., Jr., Revision of the structure and stratigraphy of the Mosquito Range and the Leadville district, Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 37–57, 1929. Result of recent detailed geologic work in this district.

4. Butler, B. S., and Vanderwilt, J. W., The Climax molybdenum deposit of Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 311–353, 1931. Detailed description of this district, which is about 13 miles (21 kilometers) north of Leadville.

5. Collins, G. E., The relative distribution of gold and silver values in the ores of Gilpin County: Inst. Min. and Met. Trans., vol. 12, pp. 480–499, 1903. A brief description of the Central City-Idaho Springs mining district and an account of the zonal arrangement of the ores.

6. Coulter, W. J., Mining molybdenum ore at Climax, Colorado: Eng. and Min. Jour., vol. 127, No. 10, pp. 394–400, 1929.

7. Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 365–388, 1924.

8. Crawford, R. D., Geology and ore deposits of the Red Cliff district, Colorado: Colorado Geol. Survey Bull. 30, 1925. Description of the Battle Mountain-Gilman-Red Cliff mining district.

9. Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894. Geologic map and brief description of the general geology of the region west of Colorado Springs.

10. DeFord, R. K., Surface structure of the Florence oil field, Fremont County, Colorado: Typical American oil fields, vol. 2, pp. 75–92, Am. Assoc. Petroleum Geologists, 1929. Description of the Florence oil field, which lies between Colorado Springs and Canon City.

11. Emmons, S. F., U. S. Geol. Survey Geol. Atlas, Tenmile district folio (No. 48), 1898. Detailed geology of the Tenmile district, which lies north of Leadville.

12. Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, 1927. Detailed description of the general geology, structure, and many of the mines.

13. Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (No. 203), 1916. Geologic map and description.

14. Fuller, M. B., General features of pre-Cambrian structure along the Big Thompson River in Colorado: Jour. Geology, vol. 32, pp. 49–63, 1924. Study of the pre-Cambrian geology of part of the Front Range midway between Boulder and Fort Collins.

[13] From Chas. W. Henderson, U. S. Bureau of Mines, Denver.

15. George, R. D., and Crawford, R. D., The main tungsten area of Boulder County, Colorado: Colorado Geol. Survey First Ann. Rept., pp. 7–103, 1909. General geology of the region that includes the Nederland tungsten district.

16. Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (No. 36), 1897. Geologic description of area south of Colorado Springs.

17. Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, pp. 186–196, 1926.

18. Henderson, Junius, The Cretaceous formations of northeastern Colorado and the foothills formations of north-central Colorado: Colorado Geol. Survey Bull. 19, 1920. Stratigraphy and structure of region on the eastern border of the Front Range.

19. Johnson, J. H., Geology of the Golden area: Colorado School of Mines Quart., vol. 25, No. 3, 1930. A summary of the stratigraphy, general geology, and structure of the region just west of Denver.

20. Lee, W. T., Peneplains of the Front Range and the Rocky Mountain National Park, Colorado: U. S. Geol. Survey Bull. 730, pp. 1–17, 1922. Defines and discusses the Flattop and Rocky Mountain peneplains of the Front Range.

21. Lee, W. T., The relation of the Cretaceous formations to the Rocky Mountains of Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27–58, 1915. Gives reasons for assuming that the Front Range region in Colorado was a geosyncline during Cretaceous time. For opposing views, see Lovering (26).

22. Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: U. S. Geol. Survey Prof. Paper 54, 1906. Detailed geology of this famous gold district.

23. Loughlin, G. F., The oxidized zinc ores of Leadville, Colorado: U. S. Geol. Survey Bull. 681, 1918.

24. Loughlin, G. F., Guides to ore in the Leadville district, Colorado: U. S. Geol. Survey Bull. 779, 1926.

25. Loughlin, G. F., Ore at deep levels in the Cripple Creek district, Colorado: Am. Inst. Min. and Met. Eng. Trans., vol. 75, pp. 42–73, 1929. Results of recent studies of the deep workings in this district.

26. Lovering, T. S., Geologic history of the Front Range, Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 58–111, 1929. General geology, stratigraphy, and structure of the Front Range and paleogeography of Colorado. For opposing views see Lee (21).

27. Lovering, T. S., Localization of ore in the schists and gneisses of the mineral belt of the Front Range, Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 233–268, 1930. General geology and structure in central part of the Front Range, where Tertiary ore deposits have been localized in pre-Cambrian rocks.

28. Mather, K. F., Gilluly, James, and Lusk, R. G., Geology and oil and gas prospects of northeastern Colorado: U. S. Geol. Survey Bull. 796, pp. 65–124, 1928. Stratigraphy, structure, and geologic map of northeastern Colorado.

29. Patton, H. B., Butler, G. M., and Hoskin, A. J., Geology and ore deposits of the Alma district, Colorado: Colorado Geol. Survey Bull. 3, 1912. Description of the Alma mining district, which lies just east of Leadville.

30. Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colorado: U. S. Geol. Survey Prof. Paper 75, 1911. Description of mining district east of Leadville.

31. Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), 1915. Geologic map and description of area between Colorado Springs and Denver.

32. Roth, Robert, Regional extent of the Marmaton and Cherokee Mid-Continent Pennsylvania formations: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 1249–1278, 1930. Correlation of some Pennsylvanian formations of Kansas and Oklahoma with beds in central Colorado and eastern Wyoming, from a study of their faunas.

33. Singewald, Q. D., Alteration as an end phase of igneous intrusion in sills on Loveland Mountain, Park County, Colorado: Jour. Geology, vol. 40, pp. 16–29, 1932.

34. Singewald, Q. D., Depositional features of the "Parting" quartzite near Alma, Colorado: Am. Jour. Sci., 5th ser., vol. 22, pp. 404–413, 1931.

35. Singewald, Q. D., and Butler, B. S., Preliminary geologic map of the Alma mining district, Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 295–308, 1930. A brief summary of the stratigraphy and structure of the mining district, with geologic map.

36. Singewald, Q. D., and Butler, B. S., Preliminary paper on the geology of Mount Lincoln and the Russia mine, Park County, Colorado: Colorado Sci. Soc. Proc., vol. 12, No. 12, pp. 389–406, 1931.

37. Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado: U. S. Geol. Survey Prof. Paper 63, 1908. Description of part of the pre-Cambrian terrane in the mineral belt of the Front Range. Includes a summary of most of the mining districts in the State.

38. Toepelman, W. C., Vanderwilt, J. W., and George, R. D., Preliminary notes on the revision of the geologic map of eastern Colorado: Colorado Geol. Survey Bull. 20, 1924. Geologic map of eastern Colorado on a scale of approximately 1:750,000, with a brief summary of the stratigraphy.

39. Ziegler, Victor, Foothills structure in northern Colorado: Colorado School of Mines Quart., vol. 12, No. 2, 1917. Describes the faulting and folding along the eastern border of the Front Range in Colorado north of Denver.

FORT COLLINS TO DENVER

By Junius Henderson and J. Harlan Johnson

This excursion follows the main road north from Fort Collins across Pierre shale. (See pl. 14.) At 5.1 miles (8.2 kilometers) from Fort Collins across the field to the left (west), there is an outcrop of fossiliferous sandstone of the Pierre. At 10 miles (16 kilometers) the derricks of the Wellington oil field are visible to the northeast and east. A large cement plant whose raw material is obtained from the Niobrara formation near by can be seen to the southeast, near the foothills. At 15.6 miles (25.1 kilometers) the road cuts through three ridges of Niobrara limestone. On the west side of the uppermost ridge specimens of *Ostrea congesta* on *Inoceramus* can be collected. On the lower (third) ridge large specimens of *Inoceramus deformis* can be obtained. The lower limestone marks the contact of the Benton and Niobrara deposits, and the Benton occupies the broad, shallow valley to the west but is covered in most places. At 16.3 miles (26.2 kilometers) the road passes through the upper Dakota hogback. The Dakota here makes two distinct ridges, which have yielded marine fossils suggesting a Lower Cretaceous (Comanche) age for the beds below the outer sandstone. At 16.9 miles (27.2 kilometers) the Morrison (Lower Cretaceous?) is exposed on the slope north of the road. It consists chiefly of

greenish shale. At the base is a pink sandstone which is probably of Jurassic age. The brick-red Lykins formation occupies the valley to the west.

At 17.1 miles (27.5 kilometers) there is a good outcrop of ripple-marked sandstones of the Lykins at a bridge over a gully. At 18.8 miles (30.2 kilometers) the gypsum layer near the base of the Lykins is exposed, and close by are the cross-bedded sandstones assigned to the Lyons sandstone. At 19 miles (30.6 kilometers) the route reaches Owl Canyon, where there is a good section of the Ingleside formation (the limestone that has been quarried, on the hillside) resting on Fountain conglomerate. At the base of the Fountain to the west, on granite, is a bed of Mississippian cherts, some of which contain fossils.

The road turns south through a valley in the Lykins formation between hogbacks of Dakota on the east and the Ingleside-Fountain ridge on the west. At 25.1 miles (40.4 kilometers) the Fountain-Ingleside ridge ends abruptly by folding and faulting, and a marked change in the strike of the Dakota ridge becomes apparent, owing to the change in depth. At 28.2 miles (45.4 kilometers) there is a good view of the Bellvue anticline, to the east, where it is bisected longitudinally by the Cache la Poudre River. The Fountain formation occupies the center of the dome. At 29.7 miles (47.8 kilometers) there is a good view of the entire fold at the town of Bellvue. At 31 miles (49.9 kilometers) the Dakota ridge is again crossed. At 32.2 miles (51.8 kilometers) the large cement plant to the north uses Niobrara limestone. At 37.3 miles (60 kilometers) is Fort Collins. At 42.4 miles (68.2 kilometers) the road crosses Fossil Creek, at the north end of Fossil Ridge.

At 43.7 miles (70.3 kilometers) the road turns west over the top of Fossil Ridge, and a stop will be made at a cut on the west slope of the ridge, at 44.3 miles (71.3 kilometers), to collect fossils north and south of the road in little draws near the top of the exposures.

The excursion then returns to the paved highway and continues south to Loveland, at 52.5 miles (84.5 kilometers). At 67.2 miles (108.1 kilometers) the excursion turns west on the road to Lyons. At 71.3 miles (114.7 kilometers) the much dissected Rabbit Mountain anticline is visible to the north. The dip on the east limb is almost vertical. Dakota sandstone may be seen swinging entirely around the rim of the fold. At 79.4 miles (127.8 kilometers) the road crosses Lykins Gulch, which is the type locality of the Lykins formation. At 81.9 miles (131.8 kilometers) the basal Niobrara is crossed. (See pl. 16.) At 83.1 miles (133.7 kilometers) a complete section of

the Niobrara is well exposed. The basal member crops out and is clearly defined in an échelon anticline and syncline. *Ostrea congesta* and *Inoceramus deformis* are plentiful in this locality. At 85.7 miles (137.9 kilometers) an outcrop of the lower Pierre is visible west of the road. At 88.1 miles (141.8 kilometers) there is a good view of Boulder from a high terrace. Valmont Butte, a basalt dike, is visible to the east. From Boulder, South Boulder Peak and the Flat Irons Peaks can be seen to the south.

After a short visit to the University of Colorado Museum to see a collection of fossils of the region the excursion continues to Denver by way of the paved road from Boulder. About 4 miles (6.4 kilometers) east of Boulder the Laramie and Fox Hills formations may be seen in a bluff north of Boulder Creek, and for several miles south of this locality the coal mines in the Laramie formation can be seen.

3 8198 309 338 539
THE UNIVERSITY OF ILLINOIS AT CHICAGO